This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

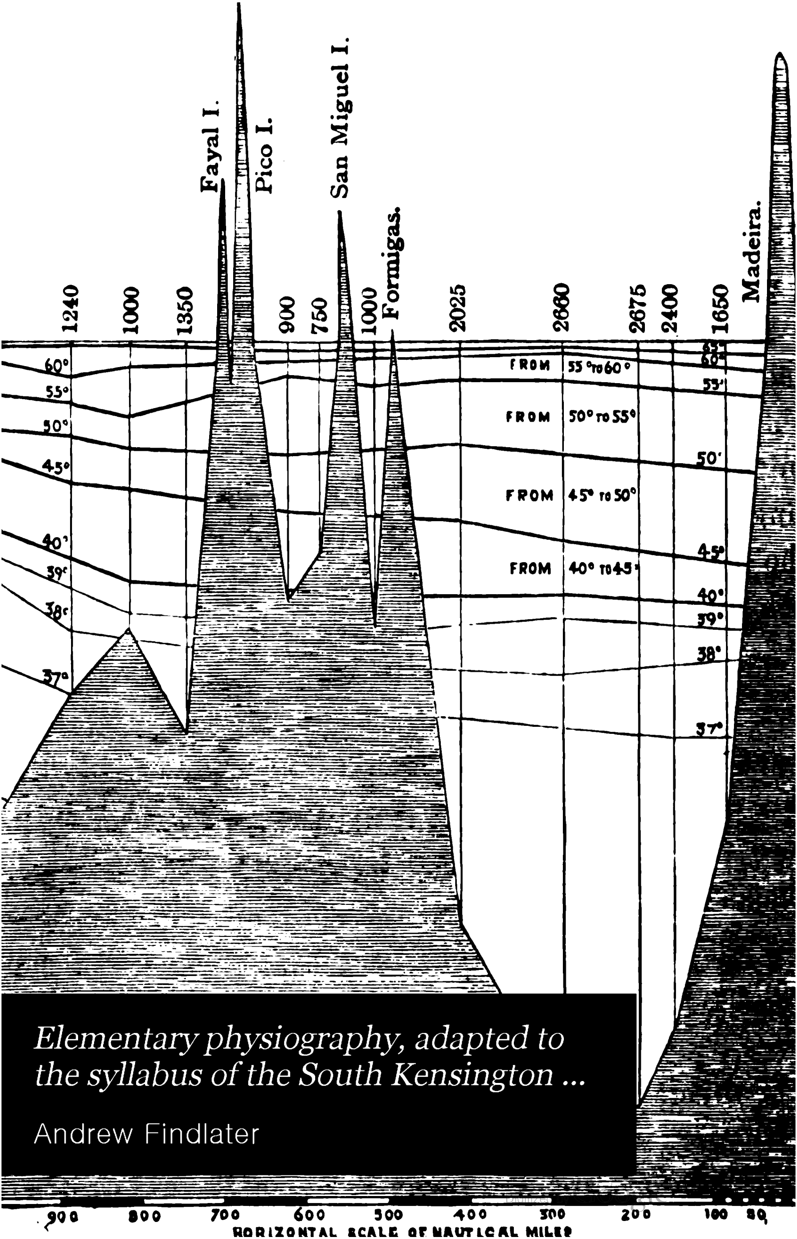
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

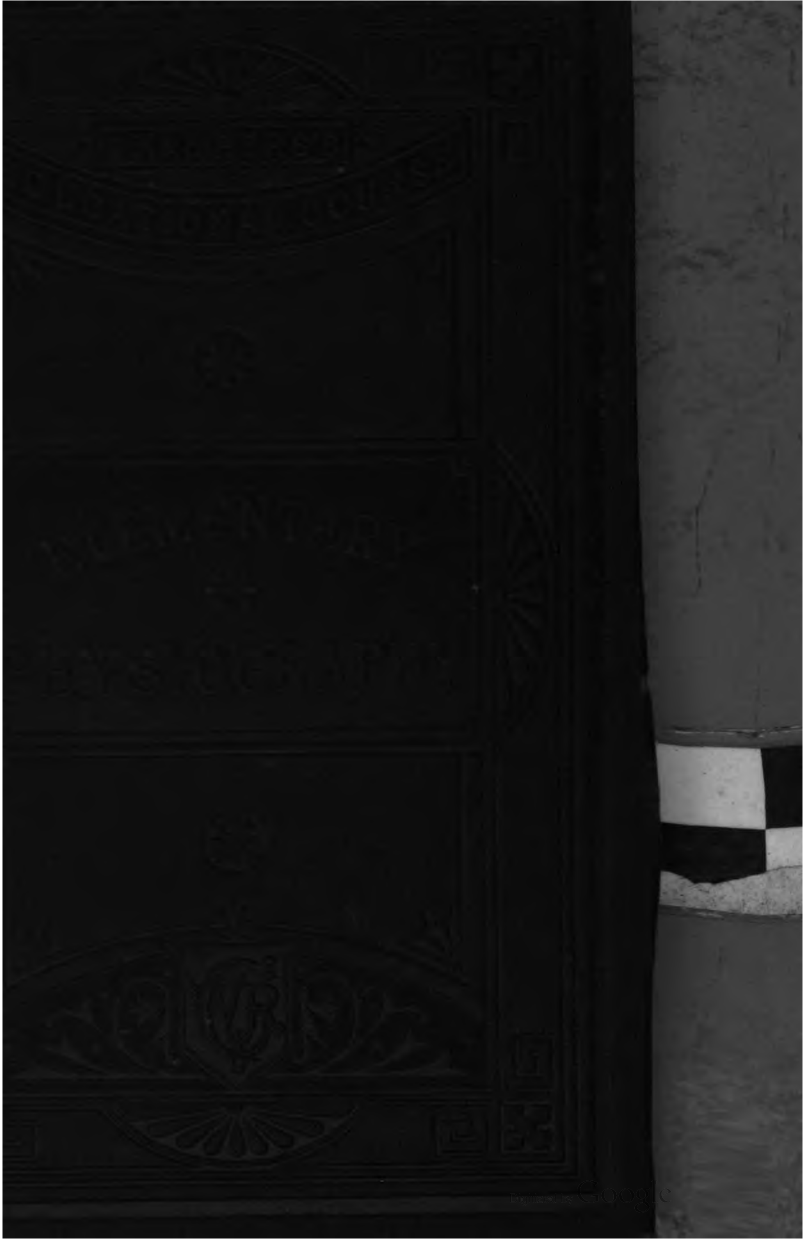
About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



Elementary physiography, adapted to the syllabus of the South Kensington ...

Andrew Findlater



ELEMENTARY
PHYSIOGRAPHY

ADAPTED TO THE SYLLABUS OF THE
SOUTH KENSINGTON SCIENCE DEPARTMENT

BY
ANDREW FINDLATER, M.A., LL.D.

W. & R. CHAMBERS
LONDON AND EDINBURGH
1881

2011. f. 12

BODLEIAN LIBRARY
10 FEB 75
OXFORD.

Edinburgh:
Printed by W. & R. Chambers.

PREFACE.

The branch of study called Physiography, as outlined in the Syllabus of the Science Department, South Kensington, is intended to give such a knowledge of the forces of nature as to enable those who have not had the advantage of a regular course of natural science, to understand the ordinary facts presented by Descriptive Geography—the principles, in short, that underlie Physical Geography.

The present text-book is adapted to the first or Elementary Stage of the syllabus, and follows pretty closely the order therein laid down. Where the ground to be gone over coincided with that treated in the text-book of *Physical Geography* published by W. & R. Chambers, the matter of that treatise has, in some instances, been transferred to the present with little change. When the same things were to be said, the Compiler did not see why he should go out of his way to say them in different words.

The treatment is throughout elementary; but, so far as it goes, it is hoped that little here taught will have to be unlearned. The geological facts are adapted from the two treatises (*Geology*, and *Historical Geology*, by James Geikie, F.R.S., author of *The Great Ice Age*) published by W. & R. Chambers. The chemical paragraphs have been revised by Professor Crum Brown, of Edinburgh University; and the whole has had the advantage of revision and suggestion by Alexander Buchan, Secretary to the Scottish Meteorological Society, especially the sections that treat of his own subject.

The Syllabus of the Elementary Stage, together with Specimens of Questions set at the annual examinations, will be found in the Appendix. It will be observed that some of the questions belong not so much to the special field of Physiography as to ordinary Descriptive and Physical Geography, which the student is expected to be already acquainted with, and on which he is warned that questions may be set.

CONTENTS.

PAGE

DIFFERENCES IN MATTER PRODUCED BY—

Gravitation.......... 1
Cohesion.......... 11
Chemical Affinity.......... 12

ENERGY.......... 21

MAGNETISM AND ELECTRICITY—

Magnetism.......... 26
Frictional Electricity.......... 29
Current Electricity.......... 33
Electro-magnetism, Magneto-electricity, Thermo-electricity..........37–40

HEAT—

Expansion by Heat.......... 41
The Thermometer.......... 43
Specific Heat.......... 45
Propagation of Heat.......... 46
Latent Heat, Sources of Heat..........53–55

CHEMICAL ACTION—

Elements and Compounds..........56–61
Breaking up of Compounds.......... 62
Water.......... 64

CRUST OF THE EARTH.......... 64
Classification of Rocks—Materials of Rocks..........65, 66
Description of Rocks.......... 69
Chief Elements composing the Earth's Crust.......... 76
Disposition of Strata.......... 77

PAGE
INTERNAL HEAT OF THE GLOBE.. 78
Volcanoes and Earthquakes.................................79–86
Upheaval and Subsidence.. 86

THE SEA—

Composition, Depth, and Bottom of the Sea.................. 88
Movements of the Ocean—Waves, Currents............ 91–101
Temperature of the Sea....................................101–105

THE ATMOSPHERE—

Height and Weight of Atmosphere......................105–108
Distribution of Pressure..108
Composition of the Atmosphere................................112
Distribution of Temperature.......................................116
Evaporation and Condensation..................................120
Rainfall, Snow, Hail, Ice...................................126–131
Air Currents...132
Climate...137
Action of Rain—Rivers, &c..138
Melting-snow—Glaciers—Icebergs.....................141–145
ATMOSPHERIC AND TERRESTRIAL ELECTRICITY..................145
CHANGES UNDERGONE BY THE EARTH'S SURFACE IN PAST AGES..........152

SYLLABUS OF THE SCIENCE DEPARTMENT, SOUTH KENSINGTON..........156
EXAMINATION PAPERS..158

INDEX...161

PHYSIOGRAPHY.

1. The matter composing our globe presents a great variety of forms; so much so, that it might seem as if there were an endless variety of distinct substances in the world. But it is not so; the number of distinct elements, as we shall see, is comparatively small; and the great variety of nature arises chiefly from the varying action of the three forces by which the elements are gathered and held together in groups or bodies. These forces are **Gravitation, Cohesion,** and **Chemical Affinity.**

GRAVITATION.

2. No appearance in nature is more familiar than that of objects falling downwards when unsupported. Some invisible force seems to draw or *attract* them towards the earth. If such an object is prevented from descending by being held in the hand, the invisible agent makes it press against the hand and feel heavy. It is from its giving heaviness (Lat. *gravitas*) to bodies that the invisible force, whatever it is, is called **Gravitation.**

3. **Every Body has weight,** and heavy and light are only comparative terms. Air itself, the very type of lightness, can be shown to have weight. If a hollow glass globe, holding a cubic foot, is emptied of air by

the air-pump and weighed, on admitting the air again, it will be found to weigh 537 grains (about $1\frac{1}{4}$ ounces avoirdupois) more than before. If instead of air, we admit hydrogen—the lightest substance known—there will still be an increase, but only about $\frac{1}{14}$th of the former, or 37 grains.

4. **Why some Bodies ascend.**—That some bodies ascend instead of falling, is no proof that they have not weight. A piece of wood or a cork held below water, mounts up when released. The wood and the cork have both weight—that is, they tend downwards; but the surrounding water is heavier than either, presses in below, and lifts them up. In a similar way, a balloon, which is filled with a gas lighter than air, and smoke, consisting of air rendered lighter by being heated, are forced upwards by the superior weight of the surrounding air. Thus it is the same force—namely, the attraction of the earth—that makes a cascade of water descend, and a column of smoke mount up.

5. **Gravitation universal.**—It was long before the attention of men extended beyond such effects of gravitation as those now instanced, where the attraction is between the earth and bodies on or near its surface. It was reserved for Newton to raise these seemingly trivial and partial facts into a grand law extending to the whole universe. It has been established by Newton and succeeding philosophers, not merely that the earth draws towards itself all bodies that are near its surface, but that every body draws every other body wherever situated; or, more generally, that *every particle of matter in the universe draws every other particle towards itself, and is in its turn drawn towards every other particle.*

6. **Why this is not readily seen.**—If this is true, you might expect that, when two lead balls are suspended

near each other, they would be seen to come together, or, at least, to incline towards each other. But no such effect is visible. The reason is that the attractive force of the earth is so overpowering that, by the side of it, the action of small bodies on one another is, in ordinary circumstances, not discernible. But by means of delicate apparatus the attraction of a heavy ball on a light one can be made manifest; and when a plumb-line is hung up near a mountain, it is sensibly drawn from the perpendicular.

7. **Attraction according to Mass.**—The relative attracting power of bodies depends upon their quantity of matter, or upon their *mass*, as it is called. This is obvious; if every particle exerts an influence, the more particles a body contains, the sum of their attractions will be the greater. Hence the overwhelming attractive force of the vast globe.

8. **Mass and Weight.**—It is usual to consider the weight of bodies as a measure of their mass; and when bodies are compared at the same place and under the same circumstances, this is sufficiently correct; but otherwise it is not so. If we suppose a man holding a pound of lead in his hand transported to the surface of the sun, the lead would feel 27 times as heavy as it did on the earth; and yet the mass is the same. There is also a slight difference in the weight of the same bodies when weighed at the poles of our earth and at the equator. Bearing this in mind, we may in ordinary cases take the weight of bodies as the measure of their mass.

9. **Specific Gravity.**—When we compare bodies of the same uniform substance, their mass must evidently be proportional to their bulk or volume. Three cubic inches of iron have three times the mass of one cubic inch. But a cubic inch of iron has less mass than a

cubic inch of lead; in fact, it takes 100 cubic inches of iron to equal in weight or mass 69 cubic inches of lead. The relative weights of bodies when the same volume is taken, are called their *Specific Gravities;* which furnish an important distinction among substances.

10. In comparing the relative weights of bodies, water is taken as the standard. The weight of a certain measure, say a cubic inch, of pure water is found, and called 1; when a cubic inch of gold is weighed, it is found to be 19 times heavier than the water; the specific gravity of gold is therefore 19. The following table gives the specific gravities of a few of the more important substances:

Platinum, coined	22·100	Flint Glass	3·375
Gold, coined	19·325	Boxwood	1·330
Mercury	13·598	Oak, old	1·170
Lead	11·352	Milk	1·030
Silver	10·474	Sea-water	1·026
Copper, hammered	8·878	Water, distilled	1·
Iron, wrought	7·788	Alcohol, absolute	·800
„ cast	7·207	Beech, dry	·590
Diamond	3·520	Cork	·240

11. **Attraction Mutual and Equal.**—The attraction or pull between any two bodies is mutual and equal. If the earth pulls a suspended stone towards it with the force of a pound, the stone is pulling the earth upward with the same force. This is seen in the case of other forces. If, sitting in a boat, you pull another boat towards you by a rope, both boats, if they are equal, will move equally toward each other. Why, then, does not the earth fall towards the stone, as well as the stone towards the earth? The cause why no such motion is seen, lies in the property of matter called *inertia.* By this property a body at rest resists being set in motion, or, if in motion, resists being stopped; and the amount of the resistance is in proportion to its mass. Hang up two weights, the one of 1 lb., the other of 100 lbs., and note the difference of pressure it requires when you push first the one and then the other, so as to give them a

certain amount of swing. Well, the pull between the earth and the stone soon sets the stone in quick motion; but the mass of the earth is comparatively so vast that the effect of the pull on it in producing motion is virtually nothing.

12. **Gravitation affected by Distance.**—If mass alone determined the attractive power of bodies, we might expect to see loose bodies near the earth fall towards the sun, whose mass is hundreds of thousands of times greater than that of the earth. But the earth prevails in virtue of its nearness. Our experience of nature generally would lead us to expect that the force of gravity would be lessened by distance, and we should be ready to conclude that the decrease would be in proportion to the distance—that at twice the distance the force would be one half. It is found, however, that the rate is more rapid; that at twice the distance, the force is only $\frac{1}{4}$th; at thrice the distance, it is only $\frac{1}{9}$th, and so on; or generally, that *the force of gravity diminishes as the square of the distance.*

It is necessary to observe here that the distance between bodies in the matter of gravity is counted, not from the nearest points, but from their centres or middle points. The distance of the globe A from B, is not *ss′* but *cc′*. The reason is, that as the several particles of A are at different distances from any part of B, their united effect will depend on their *mean* distance. When the body is of regular shape, such as a globe, or a cube, and of uniform density, the mean distance will be that of the central point.

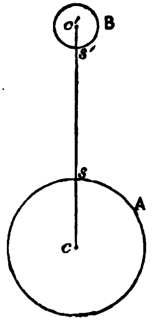


Fig. 1.

13. **Bodies become lighter at a distance from the Earth.**—According to the law stated in par. 12, bodies must become lighter as they are removed farther and farther from the earth. Let the circle (fig. 2) represent a section of the earth.

Prolong the radius CA, making AB, BD, &c. each equal to CA (which in round numbers = 4000 miles). Then the weight of a body at B is to its weight at A

as $4000^2 : 8000^2$
" $16{,}000{,}000 : 64{,}000{,}000$
" $1 : 4$

Hence 1 lb. at A becomes $\frac{1}{4}$ at B; similarly at D it is $\frac{1}{9}$ lb. But at any distances attainable by man the difference is insignificant. A body carried to the top of the highest mountain would lose weight in the proportion of

$4005^2 : 4000^2$
or $16{,}040{,}025 : 16{,}000{,}000$;

that is, a little more than $\frac{1}{400}$ of its weight at the surface. In experiments of this kind the ordinary balance with scales and weights is of no avail, as the weights are equally affected with the thing to be weighed; a spring balance must be used.

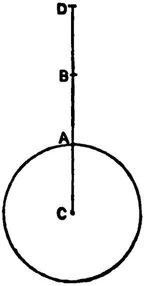


Fig. 2.

Exercise.—The polar diameter of the globe is 41,708,710 feet, and the equatorial diameter 41,848,380 feet; if a body weighing a ton at the equator were carried to the pole, what would it weigh?

14. **The Law of Falling Bodies.**—Gravity not only puts a body in motion, but *continues* to act on it with equal force after it is in motion, and thus is constantly adding to its speed. As the force of gravity continues unabated, it must give an equal addition to the speed on each successive second, and thus the motion is *uniformly accelerated.*

The locomotive continues to urge the moving train; why is the speed not uniformly accelerated, as well as that of the falling stone? Let the student think out the answer for himself.

All bodies, heavy and light, would fall equally fast, if the resistance of the air were removed. A guinea and a feather dropped in a vacuum fall to the bottom together.

15. **Rate of Acceleration.**—Observation tells us that when a body begins to fall from a state of rest, it descends 16 feet 1 inch in the first second of time. Suppose that no fall had ever been observed beyond that point, and that we had to find by reasoning what the body would do during the next second. The first consideration is, How far would the body fall, if gravity were to cease?—in other words, What velocity has it acquired? It would not be unnatural to say 16 feet (we omit the 1 inch), since that is the space it fell in the second that is ended; but reflection shows that this cannot be the case. During the first half of the second, it made very little way, and the greater part of the distance was passed over in the last half; 16 feet expresses the mean velocity, or the velocity it had at the middle of the second, and at the end it must have been moving with a velocity just double the mean, or 32 feet.

The velocity acquired, then, at the end of the first second is 32 feet; and if gravity were to cease, the body would, by the law of inertia, move over 32 feet in the next second. But gravity still acting, will make it fall another 16 feet in addition to the 32, or 48 feet in all; and will create as much velocity in addition as it created in the first second, so that if it were to cease at the end of the second second, the body would move 64 feet in the third second. Thus, during the second second, the body will fall through three spaces of 16 feet, and at the end of it will have its velocity double of what it was at the end of the first second. The whole space fallen during the two seconds will thus be four spaces of 16 feet.

We arrive at this result by reasoning, and observation proves it correct. Without giving the steps of the investigation for the succeeding spaces of time, the results may be exhibited in the following table :

Number of Seconds.	1	2	3	4	5	&c.
Velocities at the end of number of seconds, in spaces of 16 feet.	2	4	6	8	10	&c.
Spaces fallen through during each successive second.........	1	3	5	7	9	&c.
Spaces counted from beginning of fall..............................	1	4	9	16	25	&c.

The distances that bodies fall, then, do not increase simply as the times, but as the *squares* of the times. To find, therefore, how far a body will fall in any number of seconds, multiply the number of seconds by itself, and that product by 16. Thus in 7 seconds, a body will fall $7 \times 7 \times 16 = 784$ feet. The height of a precipice might be roughly measured in this way, by observing how many seconds a stone takes to reach the bottom.

16. **Formulæ for Calculation.**—The following formulæ are useful in many physical and mechanical problems : Putting h for the height or space fallen through in any number of seconds, v for the velocity at the end of that time, t the number of seconds, and g for $32\frac{1}{6}$, the velocity caused by gravity in one second, the relations of these quantities are expressed in the following formulæ, which enable us to calculate any one from the others :

$$h = 16\tfrac{1}{12} \times t^2, \text{ or (1) } h = \tfrac{1}{2}\, g \times t^2; \text{ (2) } v = g \times t \text{ and } \therefore t = \frac{v}{g};$$

$$\text{and (3) } t^2 = \frac{v^2}{g^2}$$

If in formula (1) we substitute for t^2 its value in (3)—namely, $\frac{v^2}{g^2}$, we get

$$h = \tfrac{1}{2} g \times \frac{v^2}{g^2}, \text{ or (4) } h = \frac{v^2}{2g}.$$

17. **Gravitation extended from the Earth to the Heavenly Bodies.**—When a body is made to move in a circle, it has a tendency at every point to proceed in a straight line, or fly off at a tangent, as it is called, and requires a constant force pulling it towards the centre, to keep it in its course. By observing the motions of the planets about the sun, astronomers, previously to the discoveries of Newton, had been led to believe that the planets are held in their paths by a central force proceeding from the sun, but how the force acted was not agreed upon. It was Newton who first showed that this force was identical with that which makes a stone fall to the ground. When the idea first occurred to him, it was only a conjecture, or *hypothesis;* but he proceeded to *verify* it, or put it to the test, in regard to the moon; and in this wise:

18. **Hypothesis tested by the Moon.**—The mean distance of the moon is sixty times the earth's radius. The force of the earth's attraction at that distance must therefore be 60 × 60 times less than at the surface of the earth, so that a body will fall in a second only the $\frac{1}{3600}$ part of $16\frac{1}{12}$ feet, or about $\frac{1}{20}$ of an inch. If, then, it is the earth's attraction that keeps the moon in her orbit, her motion in one second must be drawn from the straight line by this amount, neither more nor less. Now we have the means of measuring whether this is the fact or not.

Let the circle in fig. 3 represent the orbit of the moon, E being the earth and M the moon. The moon

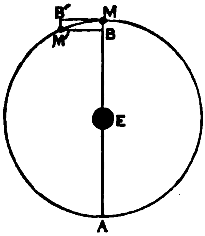


Fig. 3.

describes her whole orbit in 27 days, 7 hours, 43 minutes = 39,343 minutes = 2,360,580 seconds. The diameter of the orbit MA being 480,000 miles, the circumference is 3·1416 × 480,000 = 1,507,968 miles; so that in one second the moon will describe an arc $= \frac{1507968}{2360580} =$ ·63881 miles = 40475 inches. Let MM represent such an arc (for clearness, made much larger than due); draw M'B perpendicular to the diameter, and complete the parallelogram. Then B'M' or MB (which is the versed sine of the arc) represents the deflection of the moon during a minute. Now, in a circle, the chord of an arc is a mean proportional between the diameter and the versed sine. Here the arc, being small, does not differ sensibly from its chord; we may therefore assume

$$\text{AM} : \text{arc MM}' :: \text{arc MM}' : \text{MB}$$

$$\text{or} \quad 480{,}000 \text{ m.} : \cdot 63881 \text{ m.} :: \left\{ \begin{array}{c} \cdot 63881 \text{ m.,} \\ \text{or} \\ 40475 \text{ in.} \end{array} \right\} : \cdot 05386 \text{ in.}$$

Now $\cdot 05385 \text{ in.} = \frac{5385}{100000} = \frac{5}{100} + \frac{3}{1000}$, &c., or a little over $\frac{1}{20}$ of an inch.

19. This afforded a strong confirmation of Newton's conjecture, that the force which makes a stone fall is one with the force that draws the moon. Every subsequent application of the theory of gravitation to explain the phenomena of the universe has gone to prove its truth; and thus it has been established beyond question as a universal law of nature. It is the greatest discovery of all time.

20. **Effects of Gravitation.**—The arrangement of the matter of the universe on the great scale into globes or worlds, and these again into groups or systems, is thus due to gravitation. Were gravitation to cease acting, the whirling of the earth on its axis would scatter the matter composing it all round; and the earth and other planets, instead of revolving round the sun, would rush off in all directions into space. Every star is in all probability the centre of a group of planets, as our own sun is; and thus we have countless solar systems, each held together by this universal force.

But there are larger groups, or wholes, than solar systems. The suns themselves seem to be arranged in systems. The stars composing our firmament are thought to form a group apart, separated from other similar groups by vast blank chasms; and the several members of each group seem to hold one another in control by the mutual bond of attraction.

COHESION.

21. **How distinguished from Gravitation and from Chemical Affinity.**—While the great conglomerations of matter called worlds are held together by the force of gravitation, the smaller masses or bodies that make up a world owe their forms and consistency to two quite distinct forces—namely, cohesion and chemical affinity.

Cohesion (Lat. *co* and *hæreo,* to stick together) is the force that makes particles of matter cling to one another. It is best seen in solid bodies; it is in virtue of it that they keep their shape and resist being broken.

Were this force to cease, a stone or a piece of iron would fall asunder and become a heap of dust.

Chemical Affinity acts in a different way. Take a piece of marble and crush it to powder; however minute the subdivision, each smallest particle retains all the properties of the whole piece. The chemist dissects a body in a different way. He takes the marble and brings out of it three substances distinct from the marble and from one another—namely, a yellow metal (calcium), a black solid substance (carbon), and a gas resembling common air (oxygen). This kind of dissection is called *analysis.* The chemist, moreover, can bring together again the three substances above named, and make them re-unite and form marble (*synthesis*). It is the force that thus binds together the particles of two or more distinct substances so as to form a new substance, that is called chemical affinity. Cohesion differs from it in this, that it only makes particles of matter stick together so as to form larger masses without changing their nature. Neither cohesion nor chemical affinity will act unless the particles are brought into close contact. In this respect they differ from gravitation, which acts at all distances.

22. **Elements, Atoms, Molecules.**—When the chemist, after dissecting marble with the results above described, tries to carry his analysis farther, and to resolve the carbon or the calcium into two or more constituents, he fails; no art has yet been able to bring anything out of carbon but carbon, or out of oxygen but oxygen. Substances that thus cannot be resolved into anything else are called simple substances or *elements.* The ultimate or smallest particles of elements that enter into chemical combination are called *atoms* (Gr., indivisible); the smallest particles of any substance,

whether simple or compound, that cohere together to form a mass or body, are styled *molecules* (little masses).

[The action of chemical affinity is resumed at page 56.]

Properties of Matter depending on Cohesion.

23. **Solid, Liquid, and Gaseous States.**—These three *states of aggregation*, as they are called, are owing to differences in the strength and manner of acting of cohesion. From various facts regarding gases, the dilatation of solid bodies by heat, and the phenomena of elasticity, it is concluded that there are two opposing forces at work—an attractive force and a repulsive force; that when attraction considerably predominates over repulsion, a solid body is the result; when there is almost a balance of the two forces, we have a liquid; and when the repulsive force has the upperhand, we have a gas. From the fact that the increase of heat increases the energy of repulsion, heat and the repulsive force may be considered as virtually one and the same thing. (See par. 80.)

Many substances are seen to assume all three forms in turn. Liquid water turns at one time into solid ice; at another, into vapour or steam. Greater extremes of heat and cold have the same effects on mercury. By applying great cold and pressure, the most elastic gases—even hydrogen—have recently been rendered liquid and even solid; and it is now considered certain that all substances are capable of existing in any one of these states under certain conditions.

24. **Crystallisation.**—Put into a tumbler of pure water as much table-salt as it will dissolve; pour the solution (keeping back any sediment or undissolved

salt) into a flat plate, and set it aside where it will evaporate slowly and without agitation. As the water disappears, the salt forms into small cubes of the most exquisite finish and exactitude. Glauber salt (sodium sulphate), when it solidifies, takes the form of long four-sided oblique prisms; and in general, all inorganic substances, when becoming solid after being melted or dissolved in a fluid, have a tendency to take some regular geometrical shape, and do so when the solidification is sufficiently slow. Certain forms are characteristic of certain substances. Thus crystallised carbon (diamond) is in the shape of a solid with eight equal faces, each of which is an equilateral triangle; crystals of quartz (rock crystal) have the form of six-sided prisms, usually ending in six-sided pyramids. For the

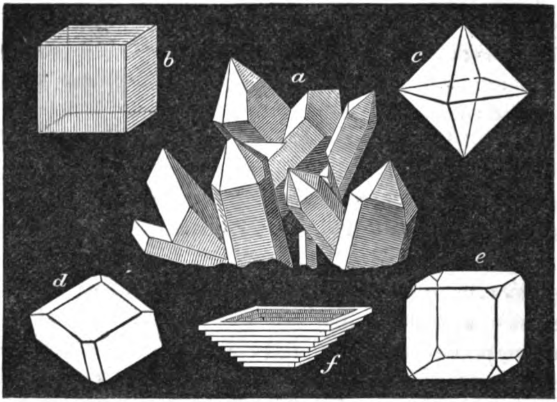


Fig. 4:

a, group of rock crystals; *b*, striation, as occasionally seen in pyrites; *c*, primary form of the diamond; *d*, calcareous spar, with truncation of edges; *e*, rock salt, primary form, with truncated angles; *f*, kitchen salt, the result of evaporation of brine (this structure consists of minute cubes piled up like courses of masonry).

character of crystallised water, see par. 246. A knowledge of these forms is an essential part of the science of mineralogy, and is of importance to the geologist.

Mineral substances without regular structure, such as glass, flint, wrought-iron, are said to be *amorphous.* A solid that was at first amorphous may become crystalline, if it is long subject to vibration. When the axle of a railway-carriage is new, the iron is fibrous in texture, and tough; but after long use it is found to have become crystalline and brittle, and hence sudden breakages.

The crystalline arrangement would seem to be the natural arrangement, which the molecules of matter assume when they can. All the facts of the case lead to the supposition that molecules do not exert the cohesive force equally on all sides, but only in certain definite directions; and that there are differences in this respect between the molecules of one substance and those of another.

25. **Resistance to Deformation.**—In solid bodies, cohesion manifests itself chiefly in resisting changes of form—*deformation* or *strain.* A body may be deformed in various ways; it may be broken, it may be bent, twisted, extended, compressed.

26. **Tenacity.**—When an attempt is made to break a body by pulling, the force with which its particles resist being torn asunder, is called its *tenacity.* In respect of this quality, bodies differ immensely. If a thread of steel of a certain thickness require a weight of 100 lbs. to break it, a thread of silver of the same thickness will break with $29\frac{1}{2}$ lbs., and one of lead with $2\frac{1}{3}$ lbs. But many circumstances modify the tenacity. The threads now spoken of were supposed prepared by 'drawing;' but if the same threads are

annealed, that is, heated to redness and then allowed to cool slowly, they will break with 54 lbs., 16½ lbs., and 2 lbs. respectively. Similar phenomena are observable in resistance to bending and cross fracture. But all three forms of resistance are modified by the property of

27. **Elasticity.**—A rod of india-rubber may be pulled out to several times its original length, or it may be squeezed end-ways into a fraction of that length; and in either case, when the force is removed, the body returns to its former shape. Similarly, a blade of steel, a rod of whalebone, a quill, may be bent largely, and recover its original form. Smear a flat smooth surface of marble or iron with a sticky coloured substance, and drop an ivory ball upon it from a height of a few feet; a considerable round patch of the ball will be found coloured, showing that the convex surface had been flattened to that extent, and yet is now as round as ever. This property in a body of yielding to a stress and then returning to its former figure when the force is withdrawn, is called *Elasticity*. Substances in which the property is very marked are styled elastic, and contrasted with *non-elastic* substances. But there is no such thing as absolute non-elasticity. Within certain limits, every body recovers from distortion; only in one substance, such as lead, the extent of this recoverable distortion is so small as to be unobservable, and in another, like steel, very wide. The amount of strain that may be recovered is called *the limit of the body's perfect elasticity*. When that limit is exceeded, the body remains permanently extended, or compressed, or bent.

28. **Compressibility.**—There are two kinds of elasticity —elasticity of shape, and elasticity of bulk; and the same body by no means exhibits the two qualities in

equal degree. When a rod of india-rubber is drawn out in length, it becomes smaller in thickness; when compressed in length, it bulges out in the middle; but when compressed in a mould, it requires great force to make it yield a very little. It is easy to understand how a body with visible pores, like a sponge, should lose in bulk by compression; but a piece of sound cork seems without pores, and yet it can be squeezed between the fingers into less than half its bulk, returning to its former dimensions when released. A gold coin is sensibly less in bulk than the blank metal was before stamping, although the gold from the first is quite solid and continuous even under the microscope. In this case the strain has gone beyond the limit of elasticity, and the loss of bulk is not recovered.

29. **Compressibility of Gases.**—It is in gases that compressibility is seen in greatest perfection. Take a cylinder full of air or any other gas, and insert an air-tight piston at the top. Before being inclosed, the gas was under a pressure of 15 lbs. to the square inch (see par. 198); now add another pressure equal to an atmosphere, and the gas will shrink into half its bulk; add yet another, and it will be reduced to a third. When the extra pressure is removed, the gas returns at once exactly to its former bulk; in other words, it is perfectly elastic. A gas follows the same law in expanding beyond its original bulk when the normal pressure is lessened; under half the compressing force, it fills twice the space. This fact, that *the volume of a gas varies inversely with the pressure,* is known as 'Boyle's Law.'

30. **Cohesion in Liquids.**—A solid is distinguished by maintaining a certain shape; and this it does in virtue of the cohesion of its molecules. A liquid always has its

free upper surface level; and for the rest, has no shape but that of the vessel holding it. Yet the force of cohesion is not altogether wanting in liquids; witness a drop of water suspended from a rod, or rolling about on a vegetable leaf. Liquids owe their fluidity to the ease with which their molecules slide over one another, while still cohering with a certain force. It is this that enables them to transmit pressure equally in all directions, a property which is the basis of the science of Hydrostatics.

31. **Viscosity.**—But all liquids are not equally fluid. Water poured into a vessel becomes level at once; treacle or tar remains heaped up at first, and requires time to spread itself out; there is sensible resistance to the sliding of the particles over one another. Such liquids are said to be *viscous.* Red-hot lava is an example of a viscous fluid. Yet there is no hard and fast line between perfect liquids and viscous liquids. Alcohol or ether is more fluid than water; in other words, water is more viscous than alcohol or ether. On the other hand, it is sometimes difficult to say whether a given substance is a viscous fluid or a solid; as in the case of a piece of sealing-wax gradually heated. Even substances so hard as to break across, sometimes show themselves to have fluidity. Cold pitch can be broken into angular pieces like bottle-glass. Take a piece, and leave it lying free on a flat surface at the ordinary temperature; after a time, it will be found spread out into a cake, as if it had been poured out molten; and yet all the while a sudden bend or blow would have made it break like glass.

32. **Adhesion.**—While cohesion acts between the particles of the same substance, adhesion acts between dissimilar kinds of matter. It is the same molecular force in both cases, but it is convenient to have a distinct name for each case. Chalk-marks on a wall, and sealing-wax on paper, are instances of adhesion.

33. **Adhesion of Liquids to Solids** takes place much more readily than that of solids to solids, because in the

case of a liquid and a solid the surfaces come into more complete contact. When the hand or a rod of metal is dipped into water, a film of the water adheres to the surface, and is borne up against its own weight; nor can any force shake it all off. Plunge a bit of gold, or silver, or lead, into mercury, and a portion of the mercury will in like manner adhere. Wherever we have *wetting*, we have a case of adhesion of a liquid to a solid.

But liquids do not always wet solids, or adhere to them. A rod coated with grease, or the wing of a water-fowl, remains dry when plunged in water. Mercury does not adhere to a porcelain cup, or to a rod of iron or platinum. The explanation is simple. There is in every case an attraction between the solid surface and the liquid, but it is opposed by the attraction of the particles of the liquid for one another, and there can be actual adhesion only when the first is stronger than the other. When the adhesive force is able to overcome the attraction of the liquid for its own particles, a part of it is separated and carried off on the surface of the solid; if the cohesion of the liquid is the stronger of the two, there is no wetting of the surface.

34. **Capillary Attraction** is only a particular effect of adhesion. A tube with a small bore, like a hair, is called a capillary tube, from *capillus*, the Latin word for a hair. If the end of such a glass tube is dipped in water, the water is seen to rise in the tube above the level of the rest of the surface. In a series of tubes of different diameters, the liquid ascends highest in the

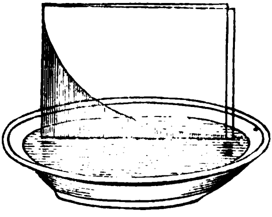


Fig. 5.

smallest; or the heights are inversely as the diameters. Water will be seen to rise in a similar way between two glass plates placed as fig. 5, with two of the upright edges touching, and the other two slightly apart. The sustained film rises higher as the plates approach, assuming the form of a particular curve. The fluid rises also slightly on the outside of the tubes and plates, and the surface of the sustained column within the tube is seen to be hollow like a cup (fig. 6).

But liquids do not always ascend in narrow tubes or spaces; it is only when they wet the solid substance that they do so. If a greasy glass tube is dipped in water; or, still better, if a clean glass tube is dipped in mercury, the liquid inside, instead of rising, sinks below the general level; the surface of the column, too, becomes convex instead of concave (fig. 7).

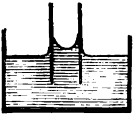


Fig. 6.

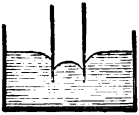


Fig. 7.

The rise or the depression depends upon the adjustment between the forces of adhesion and cohesion, as in the case of wetting. When the liquid wets the tube, the particles next its surface have part of their weight taken away or supported by adhesion, and thus a longer column is required to balance the pressure of the rest of the fluid. In cases where the cohesive attraction of the liquid particles within the tube for one another is too strong to permit them to adhere to its surface, that cohesion tends to draw them away from it, and downwards, so that a shorter column suffices to balance the general pressure.

Capillary attraction is exemplified in many familiar appearances, and plays an important part in nature. If a piece of sponge or a lump of sugar be placed so that its lower corner touches the water, the fluid will rise up and wet the whole mass. When a dry wedge of wood is driven into the crevice of a rock, and afterwards moistened with water, it will absorb the water, swell, and sometimes split the rock.

35. **Endosmose or Osmose.**—Connected with capillary attraction is *endosmose.* If two liquids be separated by a piece of ox-bladder, the one below the membrane being pure water, the other above being a solution, say of carbonate of soda, the water will pass through the membrane against gravity, and raise the solution above its former level. A smaller portion of the solution finds its way into the water. This remarkable phenomenon is known as *endosmose* and *exosmose*, or simply as *osmose.* It is not yet fully understood, but is believed to play a part in the passage of the fluids through the membranes of living animals and plants.

ENERGY.

36. Energy is defined as *the capacity of doing work.* A man does work when he makes something move against a force that resists his exertions; as when he forces a spade into the ground, lifts a spadeful of the soil some feet high, and throws it horizontally into a cart. Here the resisting forces are the cohesion and friction of the soil which oppose the entrance of the spade, gravitation which resists the vertical lifting, and the inertia of the mass which has to be overcome in the horizontal throw. It is to be carefully observed here that force may be applied without doing any work, as when we try

in vain to lift a ton-weight. No work is done unless the resisting body is made to move over more or less space.

37. **Work, how measured.**—The simplest form of work, and that with which all other kinds are compared, is that of lifting a weight perpendicularly from the ground. The lifting of a pound-weight 1 foot high is taken as the unit of work, and is called the FOOT-POUND. If, then, we lift 5 lbs. 7 feet, we have done 5 times 7, or 35 units of work. Suppose now that the work is to be done against friction, as in dragging a heavy weight along a level road; we can measure in pounds-weight the pull necessary to begin the motion, and suppose it is 50 lbs. If, then, the weight is dragged 100 yards, the work done is 300 × 50 = 15,000 foot-pounds.

38. **Energies of Nature.**—But there are other sources of energy beside the muscles of men and animals. We see the forces of nature constantly doing work. A stream of water is made to turn a wheel and grind corn or spin cotton; the wind propels ships; the energy of steam does half the work of the world. Let us attend more closely to the various shapes that the energies of nature put on.

39. **Energy of moving Bodies.**—We have seen that when a body falls freely, it will at the end, say of 4 seconds, have fallen 256 feet, and have acquired a velocity of 128 feet per second. Suppose, then, that a stone is projected upwards with a velocity of 128 feet; gravitation will now detract from its velocity every second as much as it added to it in descending; so that at the end of 4 seconds, it will have ascended 256 feet, and lost all its velocity. Here the impulse that the stone receives imparts to it an energy that enables it to lift its own weight 256 feet against gravitation; in other words, supposing it to weigh a pound, it has done 256 units of

work. Were the stone projected horizontally, it might be made to do work in some other form. *A body in motion, then, has energy, or the power of doing work.*

40. **Energy of a moving Body, how measured.**—The *amount* of energy inherent in a moving body depends on two things. 1*st*, It depends on the quantity of matter; for if the stone had been only half a pound, the units of work would have been only the half of 256. 2*d*, It also depends on the velocity, but not in the simple ratio. For by the law of falling bodies (see par. 16), the space passed over is as the square of the velocity, or $s = \frac{v^2}{2g}$; so that were the stone thrown with a velocity of twice 128 feet, it would ascend four times 256 feet. The energy then is as the mass multiplied by the square of velocity, or $e = \frac{mv^2}{2g}$. This is known as the *vis viva* of a moving body.

Energy never Annihilated, but only Transformed.

41. **Energy of Two Kinds.**—When the stone has ceased to move upwards, what has become of the energy it had at the outset? It has not perished; it has only taken another form. Suppose that by some contrivance the stone is arrested at its highest point, and left suspended; whenever it is detached, it will on its descent acquire the same velocity and therefore the same energy that it had when first projected upwards. The energy that a body has when in motion is called *kinetic* energy; when a body is so situated that, like the suspended stone, it will acquire motion if left free, it is said to have energy of position, or *potential* energy. The monkey of a pile-driver while held suspended aloft, the weight of a clock when wound up, a bent bow, have only potential energy.

The monkey descending on the head of the pile, a heavy fly-wheel in rapid motion, a cannon ball flying through the air, are examples of kinetic energy.

42. **Kinetic Energy converted into Heat.**—We have seen that the kinetic energy of an ascending stone has not perished when the upward motion ceases; it has taken the shape of potential energy, and is recovered without loss as the stone descends. But when the stone is arrested in its descent by the ground, what becomes of its energy then? Even then it is not annihilated. A body that dashes against the ground is found to be sensibly warmer than before. Thus heat is the form that the energy of the moving stone takes when arrested.

43. **Heat is Motion.**—It is now the universally received doctrine that heat consists of some kind of agitation or vibration of the molecules of matter, and that when we increase the heat of a body, we increase the force of those vibrations. When a moving mass, then, is arrested, we may conceive that the shock makes the molecules of the mass oscillate more widely and rapidly than before; the moving energy of the mass has become *molecular* energy.

44. **Molecular Energy can do Work,** as well as the energy of visible motion. For a heated body in contact with a colder communicates part of its heat to the latter —namely, puts its molecules into more rapid agitation. It may even be converted into visible energy; for, by applying the heated body to a portion of colder air, the air will sensibly expand, and may be made to move the piston of a cylinder, and do visible, mechanical work.

45. **Energy of Chemical Affinity.**—Chemical affinity is a copious source of molecular energy, often of an intense kind. Whenever different atoms unite to form

a compound, heat is evolved. The chief source of our artificial heat is combustion; and combustion is simply chemical union—the union of the oxygen of the atmosphere with the carbon and hydrogen of the fuel, producing carbonic acid and water. Chemical action is sometimes attended with vast visible energy, as when gunpowder explodes.

46. **Potential Molecular Energy.**—Before chemical affinity will act, the atoms must be brought into close proximity by being dissolved together or heated together. While two atoms are beyond the range of affinity, they are like the earth and the suspended stone; they manifest no actual energy, but they have potential energy, which becomes actual or kinetic when they are brought within range. We may thus look upon a heap of fuel as a store of potential energy, the necessary oxygen being always at hand, and only initial heat being necessary to bring the affinity into play.

47. **Energy always the result of previous Work.**—But a question arises here: The potential energy of the raised weight or the bent bow did not come uncaused; it required work—that is, expended kinetic energy, to lift the weight or to bend the bow, in order to put it in the position of advantage. Has the energy stored up in fuel cost any work? It has; and thus: Fuel consists mainly of vegetable products—wood and coal—which is simply fossil vegetable matter; and the most valuable ingredient of the fuel as a source of heat is carbon. But the chief food of plants is not carbon by itself, but carbonic acid, or carbon and oxygen combined. In this condition there is no energy possible. The two elements are in the relation of the stone and the earth when the stone is resting upon the earth; and they must be separated in order to restore their power. This work

of separation is performed in the plant. A plant absorbs carbonic acid from the soil by its roots, and from the air by its leaves; and while this is circulating through the tissues, the union of the two elements is dissolved, the carbon is fixed in the solid substance of the plant, and the oxygen is exhaled or otherwise disposed of. This chemical analysis is effected through the energy of the sun's rays; for without the heat and light of the sun, there would be no vegetation. The stores of coal, then, laid up in the strata of the earth's crust are the work of the sun's rays countless ages ago—'bottled sunbeams,' they have been called.

The power of a waterfall to do work can be traced to the same source—the energy of the sun's rays; it is by it that water is raised high into the clouds, and thus gets energy of position.

MAGNETISM AND ELECTRICITY.

48. **How distinguished from the Forces already considered.**—The natural forces as yet considered are permanent in the bodies manifesting them. Electricity and Magnetism are only temporary; they may be imparted to a body, and again vanish. The phenomena of Electricity and Magnetism form now one of the most extensive departments of physical science; we have here to consider them only in connection with the doctrine of Energy.

MAGNETISM.

49. **Magnets Natural and Artificial.**—A certain kind of iron-stone, or ore of iron, has long been known to have the power of attracting small bits of iron or steel. A bar of steel, if repeatedly rubbed with this *loadstone*, as

it is called, acquires the same properties, and is called an *artificial magnet;* while the loadstone is a *natural magnet.*

50. Poles of the Magnet.—If over a bar-magnet we scatter iron-filings, they will be found to adhere in tufts to the ends, but none at the middle. The magnetic force is thus concentrated at or near the ends, which are therefore called the *poles* of the magnet, from a remarkable property they possess. If a bar-magnet is delicately balanced on a pivot, or suspended by the middle in a thread, it will not rest till it has settled in one position, which is nearly north and south. If disturbed, it always returns to that position, and *the same end always points to the same pole of the earth.* The end that points to the north is called the north pole of the magnet, and the other end the south pole.

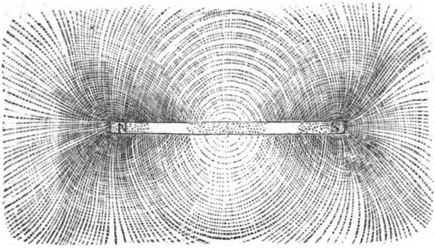


Fig. 8.

51. Poles always in Pairs—Polarity.—We cannot have a magnet with only one pole. If a magnet is broken into two, each piece becomes a complete magnet, with two opposite poles, a north and a south. This exhibition of *twin forces in opposite sides of a body is known as polarity.* It is not peculiar to magnetism, but is seen also in all electrical phenomena, one kind of electricity being always accompanied by the opposite kind.

52. **Law of Polar Action.**—Place a small bar-magnet afloat on a piece of cork in a basin of water; hold another magnet in the hand, and present its two poles successively to those of the floating magnet; the result of your experiments will be this: *Like poles repel each other; unlike poles attract each other.*

53. **Magnetic Induction.**—A bar of soft iron has of itself no power to attract another piece of iron; but in presence of a magnet it instantly assumes that power. Let a short bar of soft iron, *ns* (fig. 9), be suspended from the south pole of the magnet NS; it becomes for the time a magnet itself, its south pole being *s*. If *s* is dipped into iron filings, the filings adhere to it; but if the bar is removed from NS, the filings fall off instantly. The same effect follows when *ns* is merely brought near to S without touching it. The temporary magnetism of *ns* is said to be *induced* by the presence of NS.

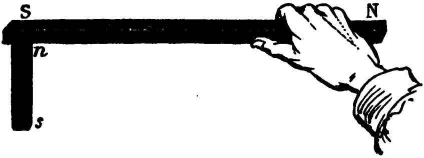


Fig. 9.

If instead of soft iron, *ns* is of tempered steel, the induction does not take place at once, but only after repeated friction with the magnet; and then it retains the property even when removed.

The great force that magnetic attraction may exert is best seen by making the magnet in the form of a horseshoe. But more powerful than any steel magnets are those of soft iron produced by the induction of the electric current (see par. 71).

54. **The Mariner's Compass.**—The directive property of magnetism furnishes that most useful instrument the

Mariner's Compass. It consists of a light magnet or needle balanced on a pivot: by always pointing north and south, it shows the quarters of the heavens when there are no other marks. It is only in rare instances that its direction is exactly north and south; the deviation from the meridian is called the *declination* of the needle, and varies in different places, and also from age to age. At Greenwich, for instance, the needle in 1880 pointed 18° 32′ west of north; but it is coming nearer and nearer to the true north by, on an average, 8′ yearly.

55. **The Earth a great Magnet.**—The theory of the directive property of magnetism is that the earth itself is a great magnet, having its opposite centres of force situated not exactly in, but near the geographical poles. The poles of this great magnet, then, attract the opposite poles of the magnetic needle, and make it lie in the direction of the line between them. The magnetism of the earth is believed to be affected by commotions on the sun's surface; it is often thrown into violent agitations, which cause the magnetic needles of observatories to vibrate from side to side. Magnetism thus forms a bond of sympathy between the members of the solar system.

ELECTRICITY—FRICTIONAL.

56. **Origin of the Name.**—When a stick of sealing-wax is rubbed with a piece of woollen cloth, it is found to attract pieces of straw or feathers, which, after touching it, seem to fly away from it. Many other substances may, in various ways, be made to manifest similar powers. To those phenomena the name of *Electricity* has been given, because amber, in Greek *electron*, was the first substance in which the property was observed.

57. Electricity of Two Kinds.—These attractions and repulsions are conveniently shown by suspending a pith ball by a silk thread, as in the figure. The ball is drawn towards the excited wax, and after touching it, is repelled from it beyond the perpendicular. A glass rod rubbed with a piece of silk produces the very same movements in the pith ball. But there is a difference; for if, while the pith ball is standing aloof from the excited wax, the excited glass rod is brought near it, it rushes to the glass. No sooner, however, has it touched, than it is repelled from the glass and flies to the wax; and thus continues to oscillate between the two so long as the excitement lasts. It thus appears that there are two different kinds of electrical excitement, and that *bodies having the same kind repel one another, while those having opposite kinds attract one another.* The excitement of a glass rod rubbed with silk used to be called *vitreous electricity,* and that of sealing-wax rubbed with flannel, *resinous;* the names now preferred are *positive* for the former, and *negative* for the latter.

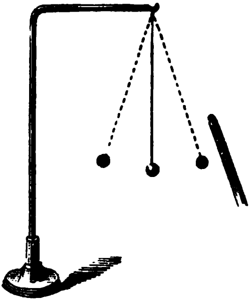


Fig. 10.

58. One Kind always accompanied by its Opposite.—A fundamental fact in electricity is, that one of the kinds can never be produced by itself, but is always attended by an equal amount of the opposite kind. Thus when positive (+) electricity is excited in glass by rubbing it with silk, the silk is found equally charged with negative (—) electricity.

59. **Hypothesis of Two Fluids.**—A convenient way of conceiving and speaking of electrical action is the hypothesis that the two principles, or 'fluids,' as they have been called, exist in all bodies in a state of union; and in this condition they give no indication of their presence—the body is *neutral.* But when the two fluids are separated by friction or otherwise, they immediately seek to be reunited, and the bodies in which the two opposite principles inhere are drawn towards each other. This hypothesis is used merely for convenience, and does not pretend to be an explanation of the real nature of electricity, which, as yet, is uncertain (see par. 91).

60. **Whence comes the Attractive Energy?**—When two bodies with opposite electricities are drawn towards each other, we have an instance of work being done. But in the instances above described, the energy that does the work is purchased, as it were, by the exertion of rubbing; and in all cases electrical excitement costs mechanical movement or the action of chemical affinity.

61. **Conductors and Non-conductors.**—If, instead of glass or sealing-wax, we rub a metal rod, holding it in the hand, we fail to get any signs of electricity. We are not to conclude from this that none has been produced; for, if the metal be held by a glass handle, it may be readily excited. The cause of the difference is, that in the case of the sealing-wax or the glass, the electricity is held, so to speak, to the spot where it is excited; in the metal, it instantly spreads over the whole surface, and escapes through the hand to the earth. Bodies that thus allow a free passage to electricity are called *conductors.* But there is no hard and fast line between conductors and non-conductors. The best conductors offer more or less obstruction to the passage of

electricity, and there is no substance that altogether bars it. The best conductors are the metals, charcoal, salt solutions, water. The chief non-conductors are dry air, shell-lac (sealing-wax), gutta-percha, india-rubber, glass, silk. A body surrounded on all sides by non-conductors has its electricity inclosed as on an island, and is said to be *insulated.*

62. **Induction.**—The leading facts of induction may be very simply illustrated thus: A brass cylinder with rounded ends, and fixed on a glass support, has pairs of piths hung at each end (fig. 11). If, now, an insulated brass ball be charged positively, and brought *near* one end of the cylinder, *both* pairs of piths will instantly diverge, and as quickly collapse when it is taken away. It is easily shown that the two ends of the cylinder are in opposite electrical states, and separated by a neutral line of no electricity. Next the positive ball there is negative electricity induced. And so it is always. A charged body induces an opposite kind of electricity on the side of another next it, and the same kind on the farther side.

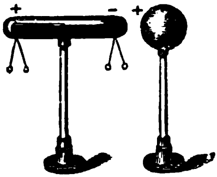


Fig. 11.

If, while the cylinder is near the positively charged ball, we touch it for a moment with the finger, its positive electricity passes off through our body into the earth, but the negative remains, being held *bound* to the positive charge of the ball. Let the ball now be removed, and the cylinder remains charged with negative electricity alone.

63. Instead of letting the induced positive electricity of the cylinder escape to the earth, let us now bring the ball gradually nearer and nearer to the cylinder; the

tendency of the negative electricity of the cylinder to unite with the positive on the ball will become stronger and stronger, until at last it is sufficient to burst through the interval of air. The two flash together with a spark and neutralise each other, and the cylinder is left charged with the positive electricity that was on the other end.

Let the student now try to explain the movements of the pith ball (par. 57) by this theory of induction.

64. **Condensed Electricity.**—By means of special apparatus ('the Leyden Jar'), two conducting surfaces may be charged with opposite electricities highly condensed or in a state of great *tension;* and then, when a conducting communication is made between them, the two principles rush together with great violence. If there is a gap in the communication, a *spark* passes through the intervening air; and if there is a bad conductor in such a gap, it may be shivered in pieces. A fine metal wire will be made red hot, or even melted, by having a strong charge passed through it; and if the human body is made part of the circuit, a peculiar shock is felt. The velocity of such a current is at least equal to that of light, or about 200,000 miles in a second. We have here the electrical excitement converted into mechanical energy, and into light and heat.

But it is in the thunder-storm that this energy of nature is seen on the greatest scale. For, as has been long known, the spark of the electric machine is, on a small scale, the very same thing as the lightning of the clouds (see par. 276).

CURRENT ELECTRICITY.

65. **The Galvanic Current.**—If a plate of copper, C (fig. 12), and a plate of pure zinc, *Z*, are put into a vessel of water, mixed with a little sulphuric acid,

and they be kept from touching, no chemical action goes on. But the moment they touch at any part, either within or out of the liquid, bubbles of gas appear at the copper plate, and they continue to form till we separate them again. We have the same result if we connect the plates, not directly, but by wires fastened to the plates. All that is visible is the production of the gas bubbles; but a hidden and most curious electric action is going on along the wire, and indeed, through the whole arrangement. For if we bring the connecting wire near a magnetic needle, the latter instantly recognises its presence and turns aside from its north and south position. Or if we break the wire, and put the two ends on the tongue, we perceive a saltish taste, which continues until we lift one of the plates out of the acid water.

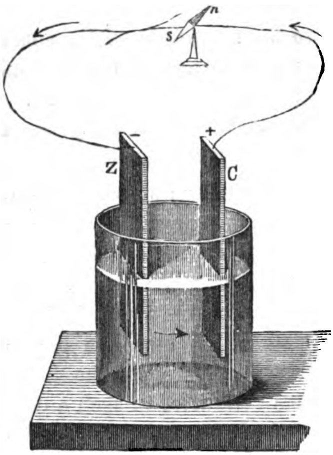


Fig. 12.

On breaking the connecting wire, we may find by a delicate electroscope that the two ends have feeble charges of opposite electricities, the wire leading from the copper being positive. There the electricities remain shut up, and the chemical action suspended, till we bring the ends together. Then the opposite electricities combine and neutralise each other; and the whole, plates and wires, become discharged or reduced to electric rest. But only for the instant; the action of the acid water sends a fresh supply of opposite electricities to each plate. So there is an incessant production and combination of the two electricities.

This constant succession of electric discharges is called a *current*, and it is said to *flow* in a *circuit* through the liquid, plates, and wire. If the circuit be *anywhere* broken, as by cutting the wire or lifting one plate out of the liquid, the *flow* of electricity instantly ceases.

66. **Difference between Current Electricity and Frictional Electricity.**—Although current electricity is of the same general nature as frictional, it differs greatly in some respects. The chief difference is, that frictional electricity has *great intensity or tension*, but is *small in quantity;* while in galvanic electricity the *quantity is large and the tension feeble.* The electricity of friction is in the static or reposing state, stored up ready to burst forth in a short sharp rush; the galvanic action is a steady torrent of the electric agent, and thus better suited for doing work. The former is potential or possible electric energy; the latter, kinetic or moving energy.

67. **Source of the Energy.**—The real source of the galvanic current is the chemical action that goes on on the surface of the zinc. Sulphuric acid and oxygen combine with zinc to form sulphate of zinc, and the energy that existed potentially in these elements when separate is set free, and appears in the current as kinetic energy.

68. **Galvanic Batteries and their Effects.**—By combining a number of pairs of plates and by other arrangements, galvanic batteries are formed which give the current any degree of strength required. The effects it may produce are many and important.

(*a*) When the current passes through a thin wire, the wire almost instantaneously becomes white hot, and in this way the powder in blasting operations, &c. is usually exploded. By the current of a strong battery, the most refractory substances (platinum, diamond, &c.) may be fused or dissipated in vapour.

(*b*) By the contrivance represented in fig. 13, the most brilliant of all artificial lights is produced. Two charcoal points, P and N, are made part of the current of a powerful battery. They are first brought in contact and then gradually separated, and the communication is kept up by a stream of white-hot particles flying from the positive to the negative pole. The light produced is almost as dazzling as that of the sun. It is difficult to keep the current steady with a battery, and the magneto-electric machine is now used (see par. 74).

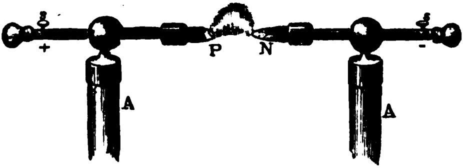


Fig. 13.

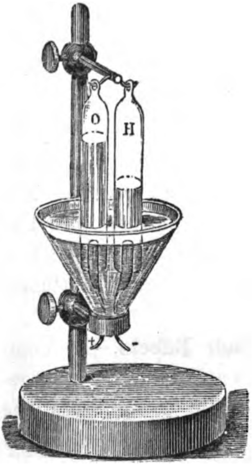


Fig. 14.

(*c*) **Electrolysis.**—If the two poles of a battery are inserted in a vessel of water, to which a few drops of sulphuric acid have been added, and a current be made to pass, the water is decomposed into its two elements, the oxygen rising up in bubbles at the positive pole, and the hydrogen at the negative. All compounds of metals with non-metals may thus be decomposed into their elements by the galvanic current. When the current is sent through a solution of nitrate of silver (a compound of silver with nitric acid), oxygen and acid will appear at the positive pole, while the silver is drawn to the negative; and if a plate of copper is soldered to the end of the negative wire, the silver is deposited in a fine film on the copper. This is *Electro-plating.*

ELECTRO-MAGNETISM.

69. Connection between Electricity and Magnetism.—If a wire is brought directly *over* a magnetic needle, and a galvanic current is sent through it, the needle is immediately deflected from its north and south position. If the direction of the current is from south to north, the north pole of the magnet turns to the left hand—that is, to the west; if the current is from north to south, the deflection is to the opposite hand. If the wire is brought *under* the needle, the effects are just reversed; a northward current causes a deflection to the east; a southward, to the west.

70. The Galvanic Current is a Magnet.—From this and other facts it is made manifest that a galvanic current is a magnet, the direction of the magnetic force being at right angles to the current. This is best seen by making the current pass through a spiral of copper wire. The spiral becomes exactly like a magnet, and if delicately

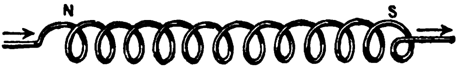


Fig. 15.

suspended will point north and south, the situation of the poles depending upon whether the spiral is left-handed, as in fig. 15, or right-handed, as in fig. 16. Two such spirals will act on one another in every way as two magnets.

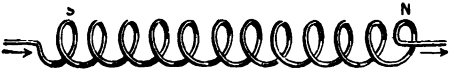


Fig. 16.

71. **The Electro-magnet.**—Moreover, if a piece of soft iron is placed within a spiral current, it becomes, *for the time*, powerfully magnetic by induction—an *Electro-magnet.* Electro-magnets are generally made in the form of a horse-shoe. The conducting wire is insulated by being covered with silk or cotton, and the strength of the magnet increases with the number of the coils. The value of an electro-magnet lies in this, that by changing the direction of the current, and by making and breaking contact, we can change the poles and make the electricity come and go as by magic. By making and breaking contact, the armature of the magnet may be made to rise and fall in rapid alternation, and thus furnishes a power capable of working any kind of mechanism (fig. 17).

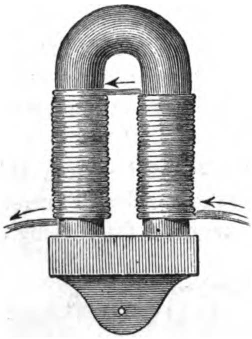


Fig. 17.

72. **The Electric Telegraph.**—In this we have the essence of the Electric Telegraph. The energy of a galvanic battery in London passes along a wire to Edin-

burgh, and there raises and depresses the armature of a magnet at the will of the operator in London, so as to make a set of prearranged signals.

73. **Current Induction.**—If, while a current is flowing along a wire, a second wire is brought alongside of it, a current immediately sets in in the second wire, but in the opposite direction to the primary. This is seen by its deflecting the needle of a galvanometer. The induced current, however, flows only for an instant and then ceases. But if the primary current is interrupted, the secondary current is renewed for an instant, although it is this time in the same direction as the primary. By renewing and then breaking the primary current, we may thus have a succession of momentary flows in the secondary wire. When the wires are arranged in two coils, the primary being within the secondary, we have what is called the *Induction Coil.* Such a coil yields a powerful stream of electricity, which has more the character of frictional electricity than of galvanic.

MAGNETO-ELECTRICITY.

74. It would seem to be in virtue of its magnetism that the primary current affects the secondary; for if the primary coil is withdrawn, and a permanent bar-magnet used in its stead, a momentary current is induced in the secondary wire when the magnet is inserted, and a current in the opposite direction when it is taken out. On this principle, *Magneto-electric Machines* are constructed, which cause induction coils to revolve over the poles of a magnet, approaching and receding, and thus keep up a constant stream of electricity. Here there is no battery, and no expenditure of zinc and acid; *the source of the current is the mechanical energy spent in driving the machine.* For large machines, steam-power is

used. It is in this form that electricity is applied for artificial lighting.

THERMO-ELECTRICITY.

75. An Electric Current produced by Heat.—As the electric current produces heat, so we may invert the order of the phenomena, and from heat derive electricity. When any two metals, unequally susceptible to heat, are soldered together, and heated at the junction, an electric current is evoked. The two metals which show this property most readily are *antimony* and *bismuth*. Thus, if a bar of antimony, A (fig. 18), be soldered to a bar of bismuth, B, and their other ends connected with a galvanometer, G, a current will pass when we heat the junction, S. Inside the couple, it flows from bismuth to antimony, and outside from antimony to bismuth, as we know by the side to which the needle swings. If cold instead of heat be applied at the junction, it will produce a current opposite in direction to what heat would. One antimony-bismuth pair has little power, but several may be joined as in a galvanic battery. The strength of the electric current thus produced by difference of temperature is very weak compared with that due to chemical action. It is as a measurer of heat—that is, as a thermometer—that the thermo-electric battery has its chief importance. Twenty or thirty antimony-bismuth pairs compactly put together are inclosed in an insulating tube, and the ends are blackened to increase the absorption of heat. Wires connect the end plates with a galvanometer. The mere approach of the hand or of a piece of ice is sufficient to deflect the needle, so sensitive is the instrument. For experiments on radiant heat it now supersedes all others.

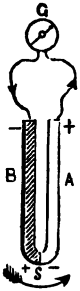


Fig. 18.

HEAT.

76. **The Extensive Part it plays.**—Heat, as we have seen, is that form of energy into which all the other kinds are oftenest and most readily transformed. No one branch of knowledge, perhaps, gives the key to so many of the appearances of nature as a knowledge of the laws of heat. In all that concerns weather and climate, for instance, heat plays the chief part. It therefore claims here our special attention.

77. **Expansion by Heat.**—What heat is has been already considered (see par. 43). One of its most marked effects is expansion. As a rule, all bodies increase in bulk when their temperature is increased. Solids expand least, gases most, and liquids to an intermediate degree. Heat an iron rod in the fire; it will be found sensibly longer and thicker than when cold. Take a glass flask, fill it with water or any other liquid, and apply a spirit-lamp; the liquid will soon begin to overflow. If a bladder three-fourths filled with air is held near a fire, it soon becomes quite stretched, and may be made to burst.

78. **Differences in Expansibility.**—Nearly every solid and liquid has an expansibility peculiar to itself. Among solids, the metals are the most expansible. Zinc expands most, platinum probably least among bodies of the metallic class. Glass, brick, porcelain, marble, and stone have small expansibilities. If a rod of iron which measures 819 lines in length when as cold as melting ice, is made as hot as boiling water, it is found to measure 820 lines. Between the freezing and boiling points, then, iron increases $\frac{1}{819}$ of its length; for the same increase of heat, glass expands only $\frac{1}{1147}$

of its length. Gases, unlike solids and liquids, have not specific expansibilities, but all undergo almost the same amount of expansion for the increase of temperature.

When heated from 32° to 212°, mercury dilates $\frac{1}{55}$ of its bulk, and alcohol $\frac{1}{8}$; air or any other gas, about $\frac{1}{3}$. An increase of 1° of temperature, therefore, increases a body of air by $\frac{1}{490}$ of its bulk.

79. **Exceptional Case of Water.**—Water presents a singular irregularity in its expansions and contractions. If boiling water is allowed gradually to cool, it follows the general law, and goes on contracting until it is within a few degrees of freezing (at 39°); it then begins to dilate, and continues to do so till it come to 32°, the freezing-point. At the moment of becoming solid, it undergoes a sudden enlargement. It is this enlargement of freezing water that causes it to burst pipes and vessels in which it is confined; it is also the reason that ice is lighter than water, and floats on the surface. Ten cubic inches of ice weigh as much as nine cubic inches of water.

In all artificial structures, especially when metal is used, allowance has to be made for the expansion and contraction of the parts through changes of temperature. But its effects in nature concern us most here. All the more important movements of the atmosphere and the currents of the ocean primarily arise from expansions and contractions through heat and cold (pars. 178, 179, 202); and to the exceptional behaviour of water, we owe it that the temperate regions of the globe are habitable (see par. 248).

80. **Rationale of Expansion.**—The mechanical theory of heat—that is, the theory that it is a mode of motion—accounts for the phenomena of expansion. If heat consists of vibrations of the particles of matter, to in-

crease it is to increase the rapidity and width of the vibrations. Thus the particles are made to urge one another farther apart, and the volume of the body is increased. The expansion of freezing water is accounted for by the hypothesis that the crystalline arrangement of the molecules occupies more room than the liquid arrangement. Some other substances expand in solidifying, notably iron and sulphur.

THE THERMOMETER.

81. **Its Construction.**—The thermometer is an instrument in which *temperature*—that is, *the intensity of heat*—is measured by the amount of expansion it produces. The most convenient substances for the construction of thermometers are found to be mercury and alcohol, or spirit of wine. For ordinary temperatures, mercury is preferable; but since it freezes at very low temperatures, alcohol is used, which cannot be congealed by any cold we can produce. The mercury or alcohol is inclosed in a glass tube with a hollow bulb at one end, the other being closed. It is then graduated by first plunging it in melting ice, and marking on the glass, or on an ivory scale attached to it, the point at which the mercury stands. This mark is the *freezing-point* of water; for water freezing and ice melting have the same temperature. The thermometer is next placed in the steam arising from boiling water, when the barometric pressure is 29·905 inches. A second mark is here made, which is the *boiling-point.*

The space between these two points is then divided into a number of equal parts, called *degrees*, and parts of the same length are set off above and below the boiling and freezing points, as far as required.

82. **Thermometers of Different Kinds.**—In the ther-

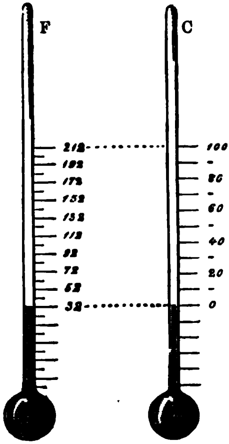


Fig. 19.—Thermometers.
F, Fahrenheit; C, Centigrade.

mometer mostly used in this country, the space between the freezing and boiling points is divided into 180 equal parts, and we begin counting at 32° below the freezing-point. A cipher is placed there, and it is called the zero or nothing-point of the thermometer. The freezing-point of water thus comes to be marked by the number 32°, and the boiling-point, which is 180° higher, by 212°. In the thermometer chiefly used on the continent, the space between the freezing and boiling points of water is divided into 100 equal parts, and the graduation begins at the freezing-point, which is marked 0°, or zero. According to this thermometer, which is called the *Centigrade*, water freezes at 0°, and boils at 100°.

The centigrade thermometer is now much employed in scientific researches in this country. To prevent any confusion arising from its being mistaken for the thermometer first described, which is called from its original maker, the Fahrenheit thermometer, the letter F. is placed after temperatures indicated by his thermometer, and the letter C. after those denoted by the centigrade.

From its zero-point each thermometer counts downwards as well as upwards; and to distinguish the degrees below zero from those above it, the former are distinguished by prefixing to them the minus sign –. Thus, mercury is said to freeze at – 37·9° F.; that is, at – 37·9° below Fahrenheit's zero.

Another scale till recently much used in Germany is that called Réaumur's, in which the freezing-point is marked 0°, and the boiling-point 80°. The degrees on this scale are thus larger than those of Fahrenheit, or even of the centigrade: 9° F. = 4° R. or 5° C; and by means of these proportions, a temperature stated in one scale may be reduced to either of the others, care being taken to allow for Fahrenheit's scale commencing, not at the freezing-point, as the others do, but 32° below it.

Examples of converting degrees of one scale into those of another:

$$20^\circ \text{ C.} = \frac{20 \times 9}{5} + 32 = 68^\circ \text{ F.}$$

$$20^\circ \text{ R.} = \frac{20 \times 9}{4} + 32 = 77^\circ \text{ F.}$$

$$68^\circ \text{ F.} = \frac{(68 - 32) \times 5}{9} = 20^\circ \text{ C.}$$

$$77^\circ \text{ F.} = \frac{(77 - 32) \times 4}{9} = 20^\circ \text{ R.}$$

Fahrenheit chose the temperature of 32° below freezing as the zero-point of his scale, because it was the lowest that had then been observed, and was considered to indicate the complete absence of heat; but it is now known that there are natural temperatures at least 90° below this; and by artificial mixtures, a cold has been produced of − 146° F.

SPECIFIC HEAT.

83. Different substances require different quantities of heat to raise them to the same temperature. This is expressed by saying that each possesses a *specific capacity* for heat, or, more shortly, a *specific heat.* The fact can be proved in a variety of ways. Thus, if we cause equal quantities of bodies which have all been raised to the same temperature, to melt ice, we shall find that a much greater weight of it will be melted by one body than by

another. Thus, mercury at 212° will melt much less ice than an equal quantity of water at the same temperature will, for the mercury has much less heat to give out, so as to produce liquefaction, than the water has.

Specific heats are generally stated with reference to equal weights, rather than to equal measures, of bodies. Thus, a pound of water in rising to a given temperature, absorbs thirty times more heat than a pound of mercury in rising to the same temperature; so that the capacity of water for heat exceeds that of mercury thirty times. Water has a greater capacity for heat than any other known substance. If the specific heat of water, then, be taken as unity, that of any other substance will be a proper fraction. Thus: Water, 1·000; turpentine, ·426; sulphur, ·203; iron, ·114; mercury, ·033.

84. **Importance of Specific Heat of Water.**—The great specific heat of water has a most important relation to the welfare of the living creatures on the globe. The sea, and other great beds of water, which spread over so large a portion of the earth, cannot in the hot months of the year become rapidly raised in temperature; in the cold seasons of the year, on the other hand, they cool slowly, and, moreover, in cooling, evolve much heat, which equalises the temperature of the air as well as that of the land.

PROPAGATION OF HEAT.

Heat is transferred from one portion of matter to another in three different ways, which are termed Conduction, Convection, and Radiation.

85. **Conduction** implies the passage of heat from one particle of matter to another in physical contact with it. It is best seen in solids, and particularly in metals, which are the best conductors. A rod of iron placed

with one end in the fire speedily becomes hot at the opposite end, owing to the conduction of heat from particle to particle along the rod. Dense bodies are generally the best conductors; light and porous ones the worst. Feathers, down, fur, flannel, and most of the fabrics used for winter dresses, owe their so-called warmth to their low-conducting power for heat. Their action is altogether negative, being limited to the prevention of the rapid escape of heat generated by the living beings whose bodies they cover.

The relative conductivities of the principal metals are exhibited in the following table:

Silver	100	Iron	12
Copper	74	Lead	9
Gold	53	Platinum	8
Brass	24	German Silver	6
Tin	15	Bismuth	2

On the same scale, the conductivity of marble would be expressed by ·8, of porcelain by ·6, of brick earth by ·55.

86. **Convection.**—Liquids and gases rapidly rise in temperature when heat is applied; but the heat passes through not by conduction, but is carried from one part to another by the particles being set in motion. If a spirit-lamp is applied to the top of a tube filled with water, the upper portion of the liquid is soon heated to boiling, while hours will elapse before even a slight degree of heat will reach any distance down the column. Water is thus seen to be a bad conductor. But if the lamp is applied at the bottom of the tube, the heat is soon felt at the top, and the whole liquid is made to boil in a few minutes. This remarkable difference is owing to a motion that takes place among the particles of the liquid. The portions resting on the bottom, being

expanded and made lighter by the heat, begin to ascend, and thus circulating currents are established which *convey* the heat to all parts of the mass. This circulation may be made visible in a glass flask (fig. 20) nearly filled with water, having a few bits of blue litmus swimming in it, and with a spirit-lamp below.

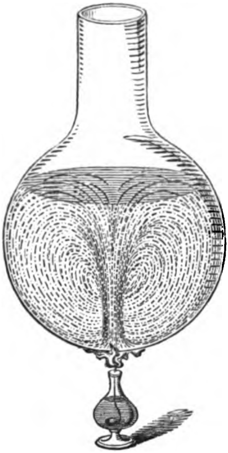


Fig. 20.

Air and other gases are raised in temperature in the same way that liquids are. They conduct heat with extreme slowness, as may be proved by applying heat to the top of an air-tight glass vessel with a thermometer suspended a little below the heated portion. But when the heat is applied from below, currents of circulation immediately begin, as in the case of a liquid.

87. **Why Wool, Down, and Snow are warm Coverings.**—Woolly coverings and furs imprison the air within their substance, and prevent it from circulating, while they afford but few points of solid contact for the direct conduction of heat. These two circumstances combined, give them their remarkable power in arresting the escape of heat; and that power is greater the finer and lighter their texture. Swan's-down is said to be the most perfect insulator of heat. From the same causes, snow is an excellent non-conductor, and, like a fleece of wool, protects the earth from any cold much below 32°.

88. **Radiation.**—When the hand is brought near a hot body, like a mass of iron, heat is felt to be darting

from it across the intervening space. This way of propagating heat is called *radiation*, because the heat streams off like rays (*radii*) of light from a luminous body. There is more, however, than an analogy between the two things. Radiant light and radiant heat are only different degrees of one and the same thing—of Radiant Energy.

89. **The Spectrum.**—When a ray of light enters a dark room through a small hole in a shutter, it forms a round white spot on the opposite wall. If now a glass prism with its edge downwards is interposed in the path of this ray, it is refracted or bent out of its path, and falls on a higher part of the wall; and what is more, it no longer forms a round white spot, but is drawn out vertically into a long rainbow-tinted ribbon, known as the *spectrum*, having the red colour at the lower end, and the violet at the upper end. This arises from the different kinds of coloured light of which white light is composed, being refracted by the prism in different degrees, the red being least refracted and the violet most. Between these extremes there are innumerable distinct kinds of rays, each having its own degree of refrangibility, and therefore maintaining a fixed place in the spectrum relatively to the others. But besides the visible spectrum, there are invisible rays beyond the red end, and it is in them that the heating power of the beam chiefly resides. There are also invisible rays beyond the violet end; and they are more powerful than the visible in producing chemical changes, as on a photographic plate.

90. **The Ether, its Waves or Pulses.**—Now, the undulatory theory of light assumes the existence of an invisible, imponderable, elastic medium called *ether*, pervading all space and filling the interstices between the molecules

of matter; it teaches that light consists of vibrations or waves excited in the ether by the luminous body, and travelling from it to the eye, just as sound arises from undulations in the air. The differences in colour of the different rays are shown to arise from differences in the length of their waves, the least refrangible having the longest waves, the most refrangible the shortest. The position of the heat-rays in the spectrum, then, shows that they differ from the coloured rays in having longer waves. So far as their cause is concerned, heat-rays differ from red rays, only as red rays differ from blue.

The intimate connection of light and heat with electricity and magnetism, and their mutual convertibility (see pars. 68 and 75), suggest that the same cause may be at the foundation of all; and the theory of Prof. J. C. Maxwell, which is considered to be all but demonstrated, makes electrical and magnetical phenomena to consist in modifications of this same invisible medium, this elastic 'jelly' (for it is conceived to be solid rather than fluid), the quivering of which causes the sensation of light.

91. **Loss of Heat by Radiation.**—Hot bodies exposed to the air lose their heat partly by convection and partly by radiation. The rate of cooling of a hot solid body, so far as radiation is concerned, is remarkably influenced by the state of its surface, and, in the case of liquids and gases, by the state of the surface of the vessels containing them. Thus, hot water placed in a tin vessel coated externally with lampblack, cools twice as fast as it does in a bright tin vessel. Hence, a kettle covered with soot is much less suited for retaining water warm, than if it had a polished metallic surface. So, also, metallic tea-pots and coffee-pots are preferable to those of porcelain and stoneware.

92. Absorption and Reflection of Rays of Heat.—When heat-rays fall on the surface of a body, they either enter it or are *reflected.* Those, again, that enter are either *transmitted,* like light through glass, or are retained and *absorbed.* It is only the rays that are absorbed that warm the body; those that are reflected off, as well as those that are transmitted, produce no effect on the temperature.

Surfaces that radiate heat best, are found also to imbibe it most readily. If a table, then, is formed of substances according to their power of radiating heat, the same table will serve for their power of absorption. The following is such a table, the radiating and absorbing power of a surface of lampblack being expressed by 100:

Lampblack	100	Tin	14
White-lead	100	Brass, polished	7
Writing-paper	98	Copper	7
Glass	90	Gold	3
Polished Iron	23	Silver	3
Mercury	23		

Since all the rays not absorbed by a surface must be reflected, this table, read from the bottom upwards, will give the same surfaces in the order of their reflecting powers. It thus appears that the best protection for the head from the burning rays of the sun is a polished metal helmet.

93. Effect of Colour on Radiation.—*Colour* has comparatively little influence on the radiation or absorption of heat so far as *obscure* or non-luminous rays are concerned. In the above table, lampblack and white-lead rank equal; and two garments of the same material, the one white and the other black, dissipate the heat of the body at the same rate, and afford the same protect from the rays of a hot stove. But in regard to *luminous* heat, the case is different. A beam of the sun contains both invisible and visible rays. Now, when such a beam falls on two pieces of cloth, one black and the other white, the effect of the obscure rays is the same on both; but the black surface absorbs also the luminous rays, while the white rejects them. The black is thus more heated than the white. As a protection against the direct rays of the sun, light-coloured clothing is thus better than dark.

94. **All Bodies radiate Heat.**—*All bodies, even the coldest, are constantly radiating off more or less heat, according to their temperature;* all are therefore both giving and receiving rays; but the warmer give more than they receive, the colder receive more than they give. A surface presented towards the open sky, with nothing to radiate or throw back the rays it is emitting, soon becomes cold; but the slightest curtain, such as a net, hung up before it, sensibly arrests the dissipation of heat. It is in this way that clouds act as warm curtains to the earth, and often prevent frosts in spring and autumn nights. The different radiating powers of bodies explain why dew is sooner deposited on some substances than on others. Those that are good radiators lose their heat most quickly, and thus condense the vapour of the atmosphere on their surfaces.

95. **Transmission of Thermal Rays.**—Some substances, it has been observed, allow heat to pass through them, as light passes through glass; such substances are called *diathermanous.* Bodies are not diathermanous and transparent in the same degree; for black glass transmits heat well, and water, which is highly transparent, is the least diathermanous of liquids. Of solid bodies, rock-salt is the most diathermanous, alum the least so. The

powers of gases and vapours to transmit radiant heat have been investigated by Professor Tyndall, with very striking results. The most important are those concerning the component elements of our atmosphere. Oxygen, nitrogen, and hydrogen transmit almost perfectly, and so does pure air, which is a mixture of oxygen and nitrogen. All the other gases absorb more or less of the rays. If the absorption of air is stated as 1, that of carbonic acid is 90, and of ammonia is 1195. But this is nothing to the absorbing power of the vapour of water. When the atmosphere is in an average state of humidity, the invisible aqueous vapour contained in it absorbs 72 times as much radiant heat as the air itself, although the quantity of the latter is 200 times that of the former. The consequences of this are of vital importance to the inhabitants of our globe (see par. 221).

Glass transmits luminous rays, but is athermanous to obscure rays; hence, a glass frame, in gardening, has been called 'a trap to catch sunbeams.' The light of the sun passes through the glass, and is absorbed by the earth as heat; but when this heat seeks to escape by radiation, the glass refuses to retransmit it.

LATENT HEAT.

96. **Heat of Liquefaction and Evaporation.**—When a solid body, such as ice, is watched whilst melting, a large quantity of heat is observed to enter it without raising its temperature in the slightest degree. This heat which enters the body serves only to melt or liquefy it, without rendering the liquid the least hotter than the solid was which yielded it. The water which flows from the melting ice is no warmer than the ice. The heat which thus renders a body liquid without warming it, is called *latent* or *insensible* heat, because it

does not affect our sensations, and does not raise the thermometer. The fact of heat becoming latent, is most decisively demonstrated by mixing a certain quantity—say an ounce by weight—of ice, or, still better, from its state of division, of snow at 32°, with an ounce of water at 172°. The result will be found to be, that the snow is all melted, and two ounces of water are procured at the temperature of 32°. The hot water, in cooling from 172° to 32°, has lost 140° of heat, which changes the snow into water, but does not raise its temperature above that originally possessed by the snow.

What we have illustrated here with ice, holds good for all solids. Each one of them renders latent a certain quantity of heat in becoming liquid, and retains that heat so long as it remains liquid; when the liquid solidifies, it is again given up. Thus, when water freezes, the 140° of latent heat all abandon it, and manifest themselves as sensible heat (see par. 239).

In evaporating a liquid, a similar disappearance of heat takes place. In boiling off a pound of water, or converting it into vapour, it can be shown by experiment that as much heat is absorbed as would have raised its temperature about 1000°, if it had not gone off in steam. Yet the water rises no higher than 212°, however hot the fire is, and the steam is of the very same temperature as the water it rises from. Thus 1000° have disappeared or become latent in the steam; and before the steam can be condensed into water again, all this heat must be given out.

The same is true of the vapour that rises slowly and silently from water at temperatures below boiling. This absorption of latent heat is the cause of the cold which always accompanies evaporation (see par. 227).

97. **Latent Heat not Lost.**—Heat which thus be-

comes latent, is not lost; it has done work in producing a change of state in the substance—in loosening the atoms from the rigid bond of cohesion, and remains a fund of potential energy, like a bent bow, ready to become heat again, or be converted into mechanical power, as in the steam-engine. This is another instance of the conservation of energy.

SOURCES OF HEAT.

Next to the sun, chemical combinations are the chief sources of heat. When two substances unite chemically, their temperature is almost always raised. When the heat is evolved so rapidly as to render the substances luminous—which most substances become when heated to a certain degree—the process is called *combustion*. *Fire* is a solid rendered luminous or incandescent by combustion; *flame* is gas at a white heat.

Animal heat has the same source as the heat of a fire or of a candle; it arises from a species of combustion. The oxygen taken into the body by the lungs unites with the carbon and hydrogen of the waste parts of the blood and solids, and converts them into carbonic acid and vapour of water—burns them, in short, and thus produces heat.

Heat can also be produced by mechanical means, such as compression, percussion, and friction. A piece of iron may be rendered hot by hammering; and axles of carriages often ignite from friction. It is found that the amount of heat thus produced is always in proportion to the mechanical energy expended in the process.

98. **Mechanical Equivalent of Heat.**—The exact relation of the heat to the work that produces it is expressed in what is called *the mechanical equivalent of heat.* It has been determined by accurate experiments

that 772 foot-pounds of work produce heat sufficient to raise a pound of water one degree in temperature; and 772 foot-pounds constitute the mechanical equivalent of heat. Another way of stating the same thing is to say, that a pound-weight falling from a height of 772 feet against the earth, generates heat sufficient to raise a pound of water one degree; or conversely, that the heat that raises a pound of water one degree in temperature, would, if it could be all used mechanically, raise 772 pounds a foot high.

CHEMICAL ACTION.

Chemical affinity, we have seen, differs from cohesion in this, that in drawing together two or more distinct substances, it makes out of them a new substance differing in kind from any of its components (see par. 21). A few examples, taken chiefly from operations going on daily under our eyes, will give a general idea of the action of this force.

99. **The Elements.**—An element was defined as a substance that has not yet been shown to be a compound. Chemists reckon at present upwards of 64 elements. Of these, about 50 are metals, and 14 are non-metals. The non-metals are:

Names.	Symbols.	Combining Weight.	Names.	Symbols.	Combining Weight.
Boron	B	11	Nitrogen	N	14
Bromine	Br	80	Oxygen	O	16
Carbon	C	12	Phosphorus	P	31
Chlorine	Cl	35·5	Selenium	Se	79·5
Fluorine	F	19	Silicon	Si	28
Hydrogen	H	1	Sulphur	S	32
Iodine	I	127	Tellurium	Te	129

Of the non-metals, five are gases at ordinary temperatures—namely, Chlorine, Fluorine, Hydrogen, Nitrogen, Oxygen. Bromine is a liquid, and with the exception of the metal mercury, is the only element that is liquid at an ordinary temperature.

The greater number of the metals are rare and of little importance except to the professional chemist; those occurring more commonly are:

Names.	Symbols.	Combining Weight.
Aluminium	Al	27·4
Antimony	Sb	122
Arsenic	As	75
Barium	Ba	137
Bismuth	Bi	210
Calcium	Ca	40
Chromium	Cr	52·5
Cobalt	Co	58·7
Copper	Cu	63·5
Gold	Au	197
Iron	Fe	56
Lead	Pb	207
Magnesium	Mg	24
Manganese	Mn	55
Mercury	Hg	200
Nickel	Ni	58·7
Platinum	Pt	197·5
Potassium	K	39·1
Silver	Ag	108
Sodium	Na	23
Strontium	Sr	87·5
Tin	Sn	118
Zinc	Zn	65·2

All the matter forming our globe is made up of these few elements, either combined to form compounds, or uncombined. Few of the elements occur uncombined, or *free*, in nature. The most prominent are oxygen, nitrogen, carbon, sulphur, gold, sometimes copper, more rarely silver.

100. **Compound Substances.**—A substance formed of two elements is called a *binary* compound; of three, a *ternary*; of four, a *quaternary*.

101. **Binary Compounds.**—The familiar substance water is an instance of a binary compound. It is a combination of two gases—oxygen and hydrogen. These two elements play a most important part in nature, and their combinations with one another and with other

elements furnish typical instances of chemical action. We therefore notice them more at length than the other elements.

102. **Oxygen.**—Oxygen exists in a free state in the atmosphere, of which it forms one-fifth by bulk (see par. 210). Oxygen is most readily obtained pure from a substance called chlorate of potash (potassium chlorate), which is made up of chlorine, potassium, and oxygen, the oxygen being more than one-third of the whole weight. When this substance is heated, the oxygen is driven off, and may be collected in jars and bottles. To the eye, oxygen is not distinguishable from air; but it is slightly heavier, and has much more active properties. In its diluted condition in the atmosphere it supports ordinary combustion and animal life. But if an extinguished taper with the wick still glowing is plunged into a jar of pure oxygen, it is suddenly rekindled, and burns with extraordinary brilliancy. If the end of a fine iron wire is tipped with burning sulphur and immersed in oxygen, the iron continues to burn with brilliant scintillations after the sulphur is consumed. Similarly, when pure oxygen is breathed instead of air, it excites the vital actions to hurtful activity.

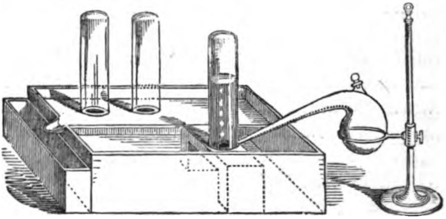


Fig. 21.

103. **Hydrogen.**—Hydrogen is rarely found free in nature, but is easily prepared by the chemist. It is a

colourless gas, and has neither taste nor smell. It is the lightest substance known, being 14·5 times lighter than air, and 16 times lighter than oxygen. Hydrogen does not support combustion ; but it burns in air with a blue flame, having little light but great heat. Compounds of hydrogen with carbon are the chief ingredients in coal-gas.

104. **Combination of Oxygen and Hydrogen.**—If now a mixture of hydrogen and oxygen is inclosed in a dry glass tube, in the proportion of one measure of oxygen to two of hydrogen, and an electric spark is sent through the mixture, an explosion takes place. The two gases disappear, and the sides of the glass are covered with drops of water. The same proof of the composition of water is afforded by burning a fine jet of hydrogen in air, and holding a dry glass vessel over it. The combination of the oxygen of the air with hydrogen forms steam, which condenses on the glass and trickles down as water. The same thing is proved when the galvanic current is used to split up water into its constituent gases (see par. 68) ; hydrogen is found at one pole of the circuit, and oxygen at the other, and always two measures of the hydrogen to one of the oxygen.

105. **Oxides.**—All the other elements combine with oxygen, and the binary compounds thus formed are styled *oxides.* The process, which is constantly going on in nature, is called *oxidation.* A familiar instance is when iron rusts in the air. Oxidation is always attended with the evolution of heat; and when the heat is so great as to produce light, it is called *combustion.* In ordinary combustion the fuel, or substance that burns, consists of carbon or compounds of carbon with hydrogen; and the products are an oxide of carbon (carbonic acid), and an oxide of hydrogen (water).

Many substances which at the beginning of this century were believed to be simple substances, have been proved to be oxides. Potash, soda, lithia, lime, magnesia, alumina, are oxides of metals more or less like silver—namely, potassium, sodium, lithium, calcium, magnesium, aluminium; and silex or flint is an oxide of silicon, a brown substance akin to carbon.

106. **Other Binary Compounds.**—Of binary compounds other than oxides, we may instance the important gaseous substance *ammonia* (NH_3), which is a compound of nitrogen and hydrogen; and common salt, which is composed of sodium and the gas chlorine ($NaCl$). Another the student may make for himself without any special apparatus. Heat the end of a rod of iron to a bright red, and press against it the end of a roll of sulphur. The sulphur immediately begins to combine with the iron, the product falling down in a molten stream. The compound, when cool, is a dull metallic-looking substance, and is known in chemistry as a sulphide of iron.

107. **Fixed Proportions.**—A fundamental fact in chemistry is that *in the same compound the ingredients are always in the same proportion.* Thus the oxygen and hydrogen in water are always in the proportion of one measure or volume of the former to two of the latter. As oxygen is 16 times heavier than hydrogen, there are 8 parts by weight of oxygen to one of the hydrogen. In the experiment described in par. 104, if either gas exceeds this proportion, the excess remains in the vessel after the union. Similarly, carbonic acid always consists of carbon and oxygen in the proportion of 12 parts by weight of carbon, to 32 of oxygen. Chemists have determined by exact experiments the relative proportions in which all the elements unite

with one another, and have agreed upon a set of numbers to express these *Combining Weights* or *Proportions.* In lists of the elements, these numbers are attached to the names of the elements, together with the *symbols* or abbreviated signs used for them (see par. 99). Such a table forms the A B C of chemical language.

108. **Multiple Proportions.**—When carbon is burned with a limited supply of oxygen, there is formed a gas called *carbonic oxide,* and when the oxygen is in excess, the resulting gas is a different substance, and is called *carbonic dioxide,* more usually *carbonic acid.* The difference in the composition of the two is exhibited to the eye in their chemical symbols :

$$\text{Carbonic oxide} = CO.$$
$$\text{Carbonic acid} = CO_2.$$

Here CO expresses not merely that carbonic oxide is composed of carbon and oxygen, but how much there is of each—namely, one combining weight, or 12 parts of carbon, to one combining weight, or 16 parts of oxygen. CO_2 expresses that carbonic acid is composed of 12 parts of carbon, and two combining proportions, or twice 16 parts, of oxygen. The oxygen in the second case is just double what it is in the first, and not any indefinite quantity more. There is no compound of carbon and oxygen with an indeterminate quantity of oxygen between 16 and twice 16. This exemplifies the law of combination in multiple proportions. The most striking example is afforded by the compounds of nitrogen and oxygen.

1. Nitrous Oxide,	containing	28	parts by	weight of N to	16	of O.
2. Nitric Oxide,	〃	28	〃	〃	32	〃
3. Nitric Tri-oxide,	〃	28	〃	〃	48	〃
4. Nitric Tetr-oxide,	〃	28	〃	〃	64	〃
5. Nitric Pent-oxide,	〃	28	〃	〃	80	〃

BREAKING UP OF COMPOUND MATTER.

109. **The Breaking up of Chemical Compounds.**—A great many of the processes, both of nature and of art, depend on the breaking up of chemical compounds. Limestone contains, as we have seen (par. 21), three elements; but it is really formed by the union of two binary compounds, each containing a proportion of oxygen—namely, calcium oxide, and carbon dioxide ($CaO + CO_2$). Take a small piece of marble or other limestone, and expose it to the heat of a brisk fire for two hours or so. If it weighed, say 100 ounces, it will now weigh only 56 ounces; the carbonic acid has been driven off, and there remains calcium oxide, known as quick or caustic lime. On this burnt limestone (lime-shell) pour some water; great heat is evolved, and the lump crumbles down. If too much water has not been used, the lime is not wet; the water has entered into chemical union with it, and forms a dry white powder, called calcium hydrate, or slaked lime. The slaked lime formed from 56 ounces of quicklime weighs 74 ounces, so that 18 ounces of water have been taken up.

To break up the two binary compounds is a more difficult process. Carbonic acid is resolved on the large scale in the vegetable laboratory of nature (see par. 47). The calcium contained in lime can only be separated by a complex process in the chemist's laboratory.

A very common means of splitting up compounds is the employment of great heat along with the presence of some substance having a strong affinity for one of the elements of the compound to be resolved. Thus, in extracting tin from the ore, called tin-stone (tin dioxide, SnO_2), the ore is placed in a reverberatory furnace along with charcoal; the highly heated charcoal, having a strong attraction for oxygen, seizes on that element in the tin-stone, flies off as carbon oxide, and leaves the tin in a liquid state. The same principle is applied in the reduction of many other ores. Sometimes heat alone is sufficient; for example, if a small quantity of red oxide of mercury is put in a test-tube, and strongly heated by a spirit-lamp, the mercury is driven off in vapour, and condenses on the cooler parts of the tube, while the rest of the tube is filled with the oxygen.

But the most powerful agent in chemical analysis is electricity. A typical example of its action is the analysis of water. It was by this means that potash, soda, lime, and other alkalies and earths, which had previously been looked upon as simple substances, were proved to be really oxides of metal.

110. **Spontaneous Decomposition.**—Many chemical compounds have a tendency to fall to pieces spontaneously. This is especially true of organic compounds. Under the influence of the vital principle, whatever it is, highly complex compounds are built up, containing numerous elements arranged in large groups. A substance found in most plants and animal bodies is sugar; and the symbols for the two kinds of sugar,

Cane sugar, $C_{12}H_{22}O_{11}$,
Grape sugar, $C_6H_{12}O_6$,

show to the eye how high the multiples of the several atoms are. The formula for quinine shows still higher complexity:

$$C_{20}H_{24}N_2O_2.$$

When we come to the albuminous compounds seen in white of egg, blood, &c., the complexity is so great, that chemists do not pretend to give any precise formulæ for the composition. In addition to the four ordinary organic elements seen in quinine, they contain sulphur, phosphorus, and iron. Such bodies are exceedingly unstable; on the least provocation, the elements separate and enter into several new groups of a simpler kind. The nitrogen appropriates a portion of the hydrogen to form ammonia (NH_3); the sulphur does the like to form sulphuretted hydrogen (H_2S). The escape of these two gases is characteristic of the process of putrefaction. Another part of this process of dissolution consists in a kind of slow combustion; the oxygen of the atmosphere unites with the carbon of the organised substance, and forms carbonic acid, which escapes as gas.

WATER.

111. The chemical symbol of water, H_2O, tells us that it is composed of two equivalents, or 2 parts by weight, of hydrogen, and one equivalent, or 16 parts, of oxygen; so that the weight of its molecule or its combining proportion is 18. Between the temperatures of 32° and 212° F., water exists in the liquid state; when cooled below 32°, it turns solid; and above 212°, it is gaseous. The remarkable facts attendant on its transitions from one state to another have been already described. See also the sections on evaporation, rain, dew, ice, &c.

CRUST OF THE EARTH.

112. **Definition of Crust.**—It was once held that the earth was mainly a molten mass with a solid rind or *crust* floating on the fluid core. That opinion has been given up, the belief now being that the earth is solid throughout, or nearly so; and the term *Crust* now implies nothing more than the solid parts of the earth so far down as we have any knowledge of them.

113. **What is a Rock?**—The various masses of matter, whether they be hard or compact like granite and limestone, or loose like gravel and surface soil, or soft like clay and peat, are all alike styled *Rocks* by the geologist.

CLASSIFICATION OF ROCKS.

114. The glimpses we get of the earth's structure in quarries, sand-pits, and railway cuttings, enable us to divide rocks roughly into two classes. By far the greater number are arranged in layers or beds piled one on the top of the other. The layers or beds are styled *Strata*, and such rocks are *Stratified*. Sandstone, sand-beds, seams of coal, chalk, &c., are instances of stratification. Granite and basalt present no such marks of bedding, and are called *Unstratified rocks*.

Another and minuter classification of rocks is grounded on the theory of how they have been formed.

115. (1) **Sedimentary Rocks.**—When we look at the layers of a shale or of a sandstone rock, we cannot resist the conclusion that they were deposited from water in the very same way that we see every day beds of sand or of mud deposited in rivers and lakes. The cohesion and hardening of the materials have been the result of time, pressure, and the infiltration of cementing substances. Strata thus formed by the settling down of matter held suspended in water are termed *sedimentary*.

116. (2) **Chemically formed Rocks.**—In the case of rock-salt, stalactites, and the like, the matter was held in water in a state, not of suspension, but of *solution*, and became solid by the chemical process of precipitation.

117. (3) **Organic Rocks.**—Chalk is mostly composed of the hard calcareous coverings of minute animals; coral is also built up by animal organisms; while peat and

coal are the remains of decayed plants. All strata of such an origin are termed *organic.*

118. (4) **Metamorphic Rocks.**—Some rocks, while partially retaining the marks of bedding, have been so altered in their nature by heat or otherwise, that their original character is obscured; such are gneiss and statuary marble. These belong to the *Metamorphic* (transformed) class of rocks.

119. (5) The Unstratified rocks are considered to have been once in a molten state, like modern lava, and are hence termed *Igneous.* Their several varieties are described in pars. 127, 128.

MATERIALS OF ROCKS.

120. **Minerals.**—A glance at a piece of coarse-grained granite shows it to be made up of a congeries of crystals of which three kinds are distinguishable. One is a gray or clear glassy substance, so hard that a knife does not scratch it; this is *quartz.* Another is known as *felspar,* and is usually of a pink or red colour; it is not so hard as the other, and may be scratched, but not easily. The third is of a dark colour, and may be split up into thin flakes with a metallic lustre; it is the well-known substance *mica.* These bodies are by no means simple substances. Quartz is crystallised silica, which we have seen to be a binary compound (see par. 105). Felspar is a compound of silica with the oxides of aluminium and potassium, and thus contains no less than four elements. Mica is still more complex, consisting of silicon and four metals (potassium, magnesium, calcium, iron), each united to its own proportion of oxygen.

Inorganic substances such as these, that have a definite chemical composition, and tend to crystallise in a definite geometrical form, are called *minerals;* and it is of these that rocks are mostly built up. There are five or six hundred different minerals, and the study of them forms a distinct branch of science, namely, Mineralogy.

The mineral ingredients of rocks are either so small or so broken, rounded, or altered, that the study of their geometrical forms as crystals gives in general little assistance to the practical geologist. There are various other tests for distinguishing them, but it requires considerable experience to apply them. The easiest way for the student to begin is to examine the forms and appearance of the more common minerals in some collection, and then to accustom his eye to the aspect presented by the same minerals when they are associated together in rocks, of which sets of illustrative specimens are readily accessible.

The most frequent minerals are :

121. (1) **Quartz**, already (par. 120) described. It occurs either in distinct crystals—mostly six-sided prisms terminated by six-sided pyramids—and is then known as *rock crystal;* or in the massive form, obscurely crystallised, called *chalcedony*. *Cairngorm*, *agate*, *cornelian*, and several other minerals, are only quartz coloured by metallic oxides. In *flint*, the silica is combined with water—hydrated silica.

122. (2) **Silicates.**—A great many minerals are compounds of silica with oxides of metals. Two of them, *felspar* and *mica*, have been already described. *Talc*, a mineral with a pearly lustre that splits readily into thin flakes, is a silicate of magnesia; as is also *serpentine*, a green, brown, or red, and variously mottled stone. *Augite*, a common mineral in trap-rocks, and *hornblende*, a component of some kinds of granite, are compounds of silica with varying quantities of alumina, lime, oxide of iron, &c. *Clay* is a silicate of alumina.

123. (3) **Sulphates.**—A compound of sulphuric acid and lime (sulphate of lime or calcium sulphate) occurs in beds as *gypsum*, or in crystals called *Satin-spar*. *Alabaster* is a fine translucent variety of gypsum.

124. (4) **Carbonates.**—Carbonate of lime (oxide of calcium + carbonic acid, or $CaO + CO_2$) occurs in the beautiful crystals known as *Calc-spar* or *Iceland-spar*. In statuary marble, it appears in minute granular crystals; and in an amorphous condition it forms common limestone, chalk, &c. *Stalactites* and *Stalagmites* are also formed of carbonate of lime.

125. (5) **Ores of the Metals.**—Iron occurs in rocks, (*a*) as the black or *magnetic oxide*, (*b*) as *hæmatite* or *specular iron ore*, and (*c*) as *carbonate of iron*, forming with earthy matter *clay ironstone*, and *blackband ironstone*. Iron pyrites is a sulphide of iron. It crystallises in the form of bright yellow cubes, often to be seen in roofing slates. *Galena* is a sulphide of lead. *Rock-salt* has been already described.

Carbon occurs as a mineral in two forms; as *diamond*, and as *graphite*, of which lead pencils are made. Combined with hydrogen, it forms coal (see par. 126).

126. **Organic Rock Material.**—Coal, peat, chalk, coral, are not strictly minerals, as they are mainly organic matter produced by plants and animals. *Coal* (see par. 140) consists mainly of carbon and compounds of carbon with hydrogen. When coal is heated, these compounds are driven off as coal gas, and what remains is mostly carbon in the form of coke. *Anthracite* is coal from which the volatile parts have been driven off by the internal heat of the earth.

Peat is a superficial and comparatively recent formation of the same chemical composition as coal, only less compact in texture (see par. 141). *Chalk* consists chiefly of the hard calcareous coverings of minute organisms, and is essentially carbonate of lime. *Coral* is the skeleton of certain small gelatinous creatures called Actinozoa, and also consists of carbonate of lime (see par. 139).

DESCRIPTION OF ROCKS.

127. **Igneous Rocks.**—Extensive tracts in Iceland are covered with beds of solid stone which are known to have issued molten from a volcano more than a hundred years ago; and the like is seen in many other places. *Recent lava,* as such a rock is called, is thus of undoubted igneous origin. But there are vast masses of unstratified rock in all parts of the world so identical in nature, that we cannot doubt of their having had the same origin, though there may be no existing crater with which they can be associated. The opinion indeed is gaining ground that much of this kind of rock did not issue from craters at all in the usual sense of the word, but was vomited forth, as it were, from cracks in the earth's crust, probably under water. These older lavas are often called *Trap-rocks.*

128. *Granite* would seem to belong partly to the igneous class, partly to the metamorphic. As a rule, it is more distinctly crystalline than the recent igneous rocks, owing probably to its being formed at greater depths, and thus having cooled more slowly and under greater pressure. But there is no distinct line of separation; granite passes into trap and trap into modern lava insensibly. In chemical composition they are essentially the same. Felspar is the basis of the whole class; but the proportion of silica varies greatly, and gives rise to many varieties. In one variety of granite, namely, *syenite,* hornblende takes the place of mica.

129. Beds of igneous rocks often occur between layers

of aqueous rocks, as if the molten matter had been poured out on the bottom of the sea, and then covered over with sedimentary matter. It is then *contemporaneous* igneous rock. In other cases, the igneous mass would seem to have been thrust with force into the midst of the aqueous strata, and is then said to be *intrusive.* When it occurs filling a rent in the strata, it is called a *dyke.* Sedimentary rocks are in general more or less altered as if by heat at their junction with igneous rocks.

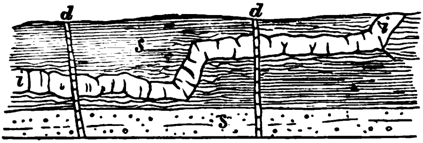


Fig. 22.—Intrusive Sheet and Dykes: *i*, igneous intrusive sheet; *d*, *d*, dykes; *s*, *s*, sedimentary strata.

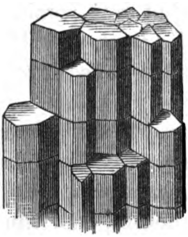


Fig. 23.
Columnar Structure.

130. **Columnar Trap.**—The older lavas often have a columnar form. This is believed to be owing to shrinkage in cooling. When a pool dries up in summer, the cake of mud on the bottom shrinks and cracks in exactly the same way.

131. **Sedimentary Rocks.**—(1) *Conglomerate* is a compacted mass of water-worn stones or pebbles. The binding material, or *matrix*, may be iron, lime, clay, sand; giving *ferruginous*, *calcareous*, *argillaceous*, *arenaceous* conglomerates. When the included fragments are angular, the term *breccia* is applied.

132. (2) *Sandstone* is compacted and hardened sand. The particles are mostly of quartz mixed with felspar, mica, They are water-worn and rounded, so that the mass

is granular but not crystalline. When the grains are coarse, we have grit, and this passes gradually into pebbly conglomerate.

133. (3) *Shale* is compacted and hardened clay. It has been deposited from water, layer upon layer, in the form of mud, and splits into thin plates or laminæ. When much mixed with sand, it becomes strictly sandstone.

134. *Clay* is not always hardened into stone. There are extensive deposits of it in a plastic state (pipe-clay, boulder clay). There are also extensive beds of sand and gravel that have continued in a friable condition.

135. *Loam* is a sandy clay with more or less lime. *Marl* is a clay or mud largely mixed with lime in the shape of minute shells; it is found in the beds of old lakes in which the inhabitants of the shells had lived.

136. **Superficial Soil.**—The chief mineral elements of soil are clay, sand, lime, and gravel, mixed with more or less decayed vegetable matter. The quality of the soil depends on the varying proportions of these ingredients (see par. 261).

137. **Organically derived Rocks.**—*Limestone* is one of the most abundant rocks. It occurs in endless variety, and is mostly of animal origin, though often much altered. *Chalk* is manifestly so. It often contains embedded in it shells and other animal remains visible to the naked eye, showing it must have been deposited in the sea. But more than this, the grains that form the mass of chalk, when examined under the microscope, are found to be the shells, broken or entire, of minute creatures called foraminifera. Myriads of these creatures people at this day the waters of the Atlantic near the surface, and as they die, their shells sink down in an incessant drizzle, adding year by year to the thickness of the gray

ooze that covers great areas of the sea bottom. Under the microscope, particles of this ooze exactly resemble particles of chalk. Mixed up with the calcareous remains in the ooze there is a quantity of silica consisting of the remains of organisms that secrete silicious coverings and skeletons. This accounts for the flint nodules in chalk, and the concretions of quartz in limestone; the particles of silex have been segregated or drawn together in course of time.

Oolite (egg-stone) is a rock built up of little, round concretions of carbonate of lime, resembling the eggs or roe of fish.

138. **Compact Limestone.**—The common limestones that form so large a part of the earth's crust—stretching over hundreds of square miles continuously, and rising to the tops of the highest mountains—are merely compacted chalk, bearing everywhere marks of their organic origin, although the minute texture has been greatly altered. Other limestones are chemical or metamorphic.

139. **Coral Rocks.**—Coral is the limy skeleton of the gelatinous creatures called actinozoa. They require a temperature of at least 66° F., and they cannot live at greater depths than about 100 feet. Coral rocks occur in three forms—namely, fringing reefs, barrier reefs, and atolls. Fringing reefs occur near the shore. Barrier reefs are found at greater distances from land, and often rise from profound depths. A barrier reef runs along the east coast of Australia, with occasional gaps, for 1200 miles, at a distance of 50 or 60 miles from the shore. Outside the reef the depth in some places exceeds 1800 feet. Atolls are ring-shaped reefs, inclosing a lagoon of still water. There is usually a great depth of water outside the reef; and as the polypes cannot live below 100 feet, the bottom on which they began to build must have

been sinking gradually for ages. The accompanying section across a coral island illustrates Mr Darwin's theory of the formation of coral reefs. The foundation was laid

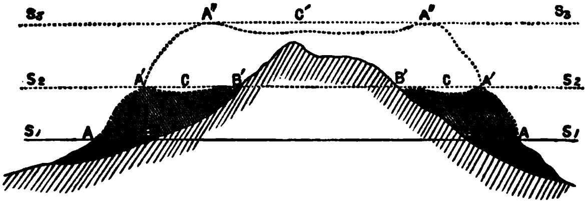


Fig. 24.—Formation of Coral Reefs.

when the level of the sea was at S$_1$, the animals beginning round the shore at a depth of about 100 feet, and raising a fringing reef up to A, B. In the meantime slow subsidence of the bottom ensues, and the building rises higher and higher. 'By-and-by the island sinks to the level S$_2$, when B′, B′, represent the shores of the now diminished island, and A′, A′, the outer edges of the reef, which has become a barrier reef; C, C, being the lagoon between the reef and the central island. We have now only to suppose a continuance of the submergence to the level S$_3$, when the island disappears, its site being occupied by a lagoon, C′—the reef, which has at the same time become an atoll, being shown at A″, A″.'

140. **Coal** occurs in beds or seams from an inch or less to thirty feet thick, associated with shales, sandstones, and other sedimentary strata. There are usually numerous separate seams one above another. The floor on which a seam rests is always a bed of shale or clay, called the *under clay*, which is believed to have been the soil in which the coal-plants grew; it yet contains many roots of those plants fossilised. The theory now held of

how the coal-beds were formed is this: That the rank and luxuriant vegetation which prevailed during the carboniferous age grew and decayed upon land but slightly raised above the sea; that by slow subsidence this thick layer of vegetable matter sunk below the water, and became gradually covered with sand, mud, and other mineral sediment; that then, by some slight upheaval of the sea bottom, or other process, a land surface was once more formed, and covered with a dense mass of plants, which in course of time decayed, sank, and became overlaid with silt and sand as before. At length thick masses of stratified matter would accumulate, producing great pressure, and this, acting along with chemical changes, would gradually mineralise the vegetable layers into coal.

It has been proved that the bituminous matter of coal is almost wholly composed of the spore cases and spores of plants allied to our club mosses and ferns.

141. **Peat** is a superficial and comparatively recent formation of the same nature as coal. It covers large tracts in Ireland under the name of *bogs*, and in England and Scotland of *mosses.* It may be seen growing, and the rate of its increase is often considerable. It consists mainly of the remains of the bog-moss (*Sphagnum palustre*). The lower parts of bog-moss die and decay, while the upper parts continue to flourish; and the decayed parts consolidate in time into a soft solid in which the fibrous structure disappears. The chemical composition is substantially the same as that of coal.

142. **Chemical Rocks.**—*Rock-salt* occurs either in thin beds or in thick masses; it is crystalline in texture, and often discoloured with impurities. Gypsum is frequently associated with rock-salt. Both may have been formed by the evaporation of water in the inland seas.

143. *Stalactites, Stalagmites, Travertine.*—When water containing carbonate of lime drops from the top of a cavern, as the water evaporates, the lime is deposited in successive layers on the floor (stalagmite), while an icicle-like rod of the lime depends from the roof (a stalactite); the two sometimes meet, forming a pillar. Travertine is a porous limestone, formed from the same cause in calcareous springs and streams. A solid object immersed in such water becomes incrusted with limestone, or *petrified*, as it is called. A similar deposit of silica, called *silicious sinter*, is formed round hot springs. Hot water charged with soda dissolves an excess of silica, which is deposited as the water cools.

144. **Metamorphic Rocks.**—Metamorphic rocks retain the marks of their original stratification, but have had their structure altered, and have become more or less crystalline.

145. *Quartz-rock or Quartzite* is sandstone in which the original quartz granules have been partially fused and blended. Where the original sandstone was largely mixed with clay-compounds, the result is a gray rock called *Grauwacke.*

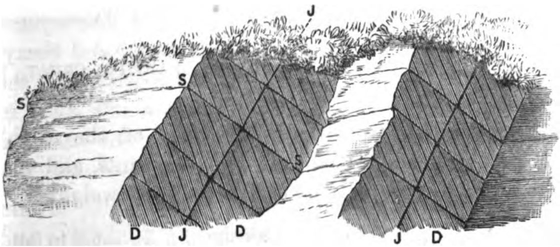


Fig. 25.—Bedding (SS), Joints (JJ), and Cleavage (DD).

146. *Clay-slate* is a fine-grained rock, generally of a

grayish-blue colour. It splits into thin laminæ; and this *cleavage* seldom coincides with the original stratification, but crosses it at all angles. It is thus distinct from the lamination of shale.

147. *Schists.*—There are many varieties of schists—mica-schist, talc-schist, &c., according to the predominant mineral. They all agree in being crystalline, and in having the constituent minerals arranged, not confusedly as in the igneous rocks, but in layers parallel to the original bedding. This particular texture is called *foliation.*

148. In *Gneiss*, which consists of quartz, felspar, and mica, the foliation is well marked, but many beds of gneiss can be traced until all marks of bedding are lost; the rock becomes gradually more crystalline, and at last passes into a true granite, as if part of an aqueous rock had been completely fused *in situ.* Granite may thus in some cases result from metamorphism carried to a high degree.

149. **Crystalline Limestone.**—In this the traces of the original organisms are obliterated. *Saccharoid* marble is a fine variety, resembling loaf-sugar in texture. *Dolomite* is an altered limestone, in which carbonate of magnesia has partly replaced carbonate of lime.

CHEMICAL ELEMENTS OF WHICH THE EARTH'S CRUST IS CHIEFLY COMPOSED.

150. According to Roscoe, the bulk of the earth's solid crust is made up of only *eight* elements, and that in the following proportions of 100 parts by weight:

Oxygen	44·0 to 45·7		Calcium	6·6 to 0·9	
Silicon	22·8	" 36·2	Magnesium	2·7	" 0·1
Aluminium	9·9	" 6·1	Sodium	2·4	" 2·5
Iron	9·9	" 2·4	Potassium	1·7	" 3·1

Oxygen, in addition to entering into rocks, makes up $\frac{8}{9}$ths by weight of all the water on the globe, and nearly $\frac{1}{4}$ of the atmosphere. On the supposition, then, that the core of the earth is composed of the same materials as the crust, we may reckon that *one-half the weight of our globe is oxygen.*

DISPOSITION OF STRATA.

151. We must conceive the layers of sedimentary rocks to have been laid down at first horizontally, or nearly so. In most cases, however, the original disposition has been disturbed. The strata are found at all degrees of inclination or *dip*, and frequently bear marks of having been bent, dislocated, and contorted.

Fig. 26 gives an idea of what frequently occurs. Beds of limestone are seen coming to the surface—*cropping out*—at *l*, *l*, *l*, among beds of shale and sandstone. The two outcrops at *l*, *l*, on the left are evidently portions of one and the same stratum; and to explain how they come to be so disposed, we have to conceive that, when originally disturbed, the strata extended in a bend or undulation, as indicated by the dotted lines; and that these portions were afterwards worn away by denudation.

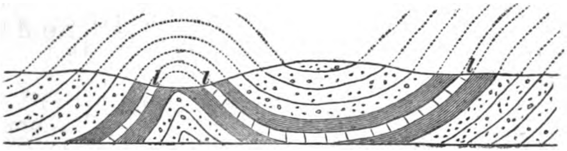


Fig. 26.—Effects of Bending and Denudation.

152. **Unconformability.**—When one set of rocks is found resting on the upturned edges of a lower set, the former are said to be unconformable to the latter. In

the accompanying section (fig. 27), *a*, *a*, represent beds of sandstone resting on the upturned edges of limestone,

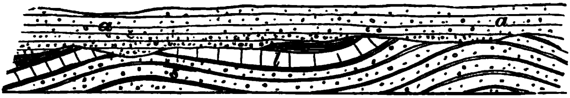


Fig. 27.—Unconformability.

shale, and sandstone, *l*, *s*. This pictures an immense lapse of time. We must first think of the deposition of the lower strata, one after another, in a horizontal position; then came the time of disturbance, when they were crumpled up into great convolutions; next began the process of planing away the tops of the convolutions; and finally, after a long lapse, another series of depositions succeed, terminated by an upheaval. The agents by which all this crumpling up and planing away have been effected, will be considered afterwards.

INTERNAL HEAT OF THE GLOBE.

153. **Heat increases with Depth.**—At a certain distance below the surface of the earth there is everywhere a line where the heat of summer and the cold of winter are unfelt. The depth of this stratum of constant temperature varies with the climate and the nature of the rocks, from 20 to 50 feet. Beyond this depth, the heat is found to increase pretty regularly. The rate varies in different places, but the average for the whole globe is about 1° F. for every 50 feet of descent. This result has been arrived at from the numerous observations made in mines, in boring for artesian wells, and similar operations; and we cannot be sure that this rate holds beyond the limit of the observations, which is not over 3000 feet. But assuming that it does, at a

depth of 12,000 feet, we should have the temperature of boiling water; and, at 50 miles, the heat would be more than sufficient to fuse the most refractory substances known.

154. **The Interior not Fluid.**—It does not follow that the interior of our earth is actually in a fluid state. It is believed that the pressure of the superincumbent masses is sufficient to keep the interior matter in the solid state, notwithstanding the regular increase of heat. Were it not so, the attraction of the sun and moon would cause tides on the internal molten ocean, and the outer crust would partake of the undulations; but this we know is not the case. But although the earth is mainly solid, it is thought probable that some way below the surface there is a stratum of a honey-combed structure having cavities containing molten matter; and it is to this cavernous region that we are to look for the explanation of volcanoes and earthquakes.

155. **Volcanoes.**—A volcano is a conical hill or mountain, composed of matter that has been thrown out (*erupted*) from the interior of the earth. In the top is a cup-shaped cavity, called the *crater*, through which the erupted matter issues. When a volcano is *dormant* (which is different from being *extinct*), there is nothing to be seen externally but a light cloud of vapour floating on the top. On looking down into the cavity, jets of steam are seen issuing from various points in the flat space at the bottom, and often cavities full of red-hot lava. But at irregular intervals outbursts of violent activity occur. These outbursts are preceded by well-known symptoms—subterranean rumblings, tremblings of the ground, and fitful jets of steam and other vapours.

Fig. 28 is an ideal section of a volcanic mountain in eruption, and will give a notion of what takes place.

'*a* is the funnel or neck of the volcano filled with lava; *b*, *b*, the crater. The molten lava is highly charged with

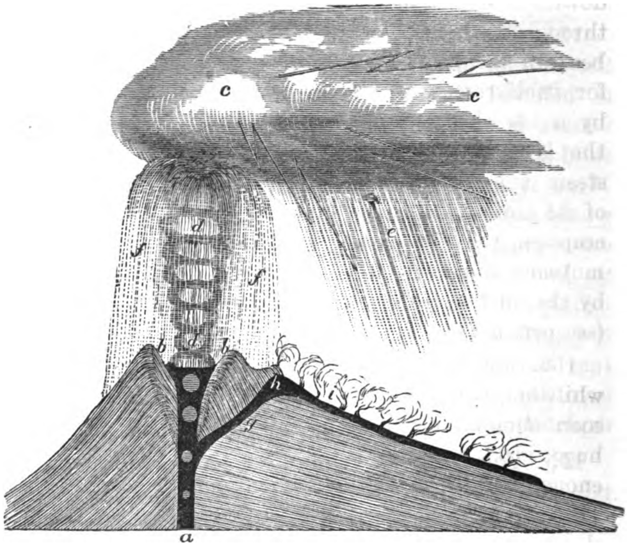


Fig. 28.—Diagrammatic Section of Volcano.

elastic fluids, which continually escape from its surface with violent explosions, and rise in globular clouds, *d*, *d*, to a certain height, after which they dilate into a dark cloud, *c*. From this cloud showers of rain, *e*, are frequently discharged. Large and small portions of the incandescent lava are shot upwards as the imprisoned vapour of water explodes and makes its escape, and, along with these, fragments of the rocks forming the walls of the crater and the funnel are also violently discharged; the cooled bombs, angular stones, and *lapilli*, as the smaller stones are called, falling in showers, *f*, upon the exterior parts of the cone or into the crater, from which they are again and again ejected. Most frequently the great weight of the lava inside the crater suffices to break down the side of the cone, and the molten rock escapes through the breach. Sometimes, however, it issues from beneath the base of the cone. At other times, finding for itself some weak place in the cone, it may flow out by a lateral fissure, *g*. In the diagram, *i*, *i* represents the lava streaming down the outward slopes, jets of steam and fumaroles escaping from almost every part of its surface. Forked lightning often accompanies an eruption, and is supposed to be generated by the intense mutual friction, in the air, of the ejected stones, as well as by that of the steam that always accompanies an eruption (see par. 158).

156. *Lava-streams.*—Lava issues from the crater white-hot, and flows like melted iron; but the surface soon darkens, hardens, and cracks into fragments like huge black cinders. Before long the surface is firm enough to walk upon, while the mass below is still fluid. The end of a lava-stream has been seen creeping on slowly nine or ten months after the eruption had ceased; and the interior of the mass may retain its heat for twenty years and more. The mass of matter ejected is sometimes enormous. In 1783 the volcano of Skaptur Jökul in Iceland sent forth two streams of lava, the one fifty miles long, and in places fifteen broad; the other forty miles long by seven broad. In some places the lava exceeded 500 feet in thickness.

157. *Volcanic Ash.*—Not less important than the lava are the *scoriæ* and ashes ejected from volcanoes. The fine dust called *ash* may arise partly from the trituration before spoken of; it may also partly consist of small particles of the molten lava carried up

by the rush of steam—lava *spray*, in short, cooled in the air.

158. *Volcanic Steam.*—Steam plays an important part in volcanic eruptions; if indeed it be not the chief cause of them (see par. 162). The steam that issues from a volcano becoming cooled in the air, condenses and falls in torrents of rain. This, mingling with the falling and fallen ashes, descends the slopes in avalanches of mud. It was such *mud-lava* from Vesuvius in 79 A.D. that overwhelmed the cities of Herculaneum and Pompeii.

159. *Bands of Volcanic Action.*—About 400 active volcanoes have been enumerated. They are mostly arranged in lines or *bands*, and as a rule are placed not far from the sea, being partly along the margins of continents, and partly in chains of oceanic islands. The Pacific Ocean is bounded by an almost unbroken line of active volcanoes. Beginning in the New South Shetlands, where there is an active volcano in lat. 62° 55′ S., we pass to Tierra del Fuego, and then on to the Andes, which are, throughout their whole course, volcanic. The line is continued northwards by the burning mountains of Mexico and of North-western America, and the Aleutian Islands carry the chain across to Kamtchatka on the Asiatic side. Here turning southwards, the line may be traced through the Kurile Islands, Japan, Formosa, the Philippines, Moluccas, New Guinea, and the Solomon and New Hebrides groups, to New Zealand. From Celebes, a branch proceeds in a north-westerly direction through Java and Sumatra, to Barren Island in the Bay of Bengal; and even beyond this we find a region in Northern India subject to earthquakes, which may lead us, on the one hand, to the volcanic region in the Thian-shan Mountains, or, on the other, through Asia Minor to the Greek

Archipelago, Sicily, Naples, and on to the Canaries. Two-thirds of the active volcanoes are on islands, and the greatest development of volcanic activity in the globe is manifested in Java and the adjacent islands. Java has a line of 45 vents, 28 of which have been seen in eruption. The only important line of volcanic mountains at a distance from the sea is in the range of Thian-shan, in Central Asia.

160. **Earthquakes.**—The quakings of the earth are of all degrees of strength, from a slight tremor to the most violent commotion. During a heavy shock, trees sway from side to side like the masts of a ship in a swell. Buildings rock to and fro, and are knocked down. Sometimes the ground is rent open in great tracts, miles in length, which engulf whatever is on the surface. The sea is observed to retreat for hundreds of yards, and then to return in a huge billow that bursts over the land, annihilating entire towns. Sometimes abnormal waves come rolling to the shore, caused by an earthquake under the bed of the ocean at too great a distance to be propagated through the solid crust.

Earthquakes of a mild kind are not unknown in Great Britain. The part where they are most frequently experienced is a district in Perthshire, of which Comrie is the centre. The most violent earthquake experienced in the Old World was that which destroyed the city of Lisbon in 1755. A hollow thunder-like sound was first heard, and was immediately succeeded by a violent upheaval of the ground, so that in three minutes the greater part of the houses were overturned. Other shocks followed, and altogether 60,000 lives are estimated to have been lost in Lisbon and its neighbourhood. The ocean first retreated and then advanced in a mass fifty feet high, and a violent flux and reflux of the ocean extended along the coasts of the Peninsula, and was felt as far as the British Islands.—In 1868, a terrible earthquake devastated Peru and Ecuador. The convulsion extended the length of 2000 miles, reducing towns and cities to ruins, and burying the inhabitants by thousands. The shipping in the ports was overwhelmed and wrecked. An American man-of-war was carried a quarter of a mile inland, and lost only one man.—In 1880–81, the city of Agram, the island of Ischia, and that of Chios, were the scenes of violent earthquakes. In Chios upwards of 250 shocks were experienced, 9000 persons perished, and barely twenty houses were left habitable in the whole island.

161. *Earthquake Bands.*—The regions of the globe where earthquakes are most frequent and violent are those where active volcanoes exist. The most noted earthquake district in the New World lies along the coast on the west side of the Andes, and on the northern declivity of the mountains of Venezuela. In the Old World the earthquake district of the Mediterranean and of Central Asia extends from the Azores and Canaries on the west to Lake Baikal on the east. Within this zone occurred the great earthquake of Lisbon, and the many disturbances that have shaken Italy. An earthquake district connected with Iceland embraces the north of France, Great Britain, Denmark, and Scandinavia.

162. *Causes of Earthquakes and Volcanoes.*—The two phenomena are evidently closely associated. Not only do they occur in the same regions, but they coincide in time. During violent volcanic eruptions, earthquakes take place; and during earthquake disturbances, volcanoes are observed to be more active. Hence the two things are most likely owing to the same cause. A growing belief among geologists is, that the chief cause

of volcanic eruptions at least is the expansive force of steam. The crust of the earth, though upon the whole solid, is believed to contain cavities or lakes of molten rock, and volcanoes are orifices of communication between them and the surface. Into these cavities, water, sinking down through crevices from the ocean or the land, must be constantly finding its way; and the steam thus generated exerts such enormous pressure as to force the molten rock to the surface, itself mingling and escaping along with it. While under pressure, the molten matter becomes highly charged with steam condensed in its substance; and as it approaches the orifice, and has the pressure removed, what happens is comparable to the evolution of carbonic acid in soda-water when the cork is removed, which is often violent enough to eject the whole contents of the bottle into the air—a veritable eruption. Owing to the constant shrinking and cracking of the crust, masses of water must frequently be precipitated suddenly into these hot caverns, and the explosion of steam will produce a concussion, and, where there is no vent, may be sufficient to convulse and rend the superincumbent strata.

Another cause of earthquakes has been suggested in the falling of large rock masses from the roofs of subterranean cavities, or in the cracking of the rocky strata when bent or crushed in the process of shrinking.

163. *Extinct Volcanoes.*—Every considerable region on the globe bears marks of former volcanic action now extinct. During the geological history of our planet, the seat of activity seems to have often shifted, the eruptions dying out at one place only to break out fresh at another. In some places, as in Auvergne in France, there are yet to be seen cones and craters and descending currents of lava as perfect and fresh as if they had been

in activity a few years ago. In other places, as in the British Islands, the volcanic rocks have been so long exposed to the waste of the elements, that no actual crater is now to be seen. There is evidence, however, that a chain of volcanic islands extended from the north of Ireland to Iceland, and formed the hills of Antrim, Mull, Eigg, Skye, Faroe, and the older parts of Iceland. The present active volcanoes of Iceland are probably a remnant of this band (see par. 127).

UPHEAVAL AND SUBSIDENCE.

164. It sometimes happens that after an earthquake the level of the ground remains altered over a considerable area. Thus, in 1819, the Great Runn of Kutch in Hindustan was depressed over an area of several square miles, so as during the monsoons to become a salt lake. In New Zealand, on the other hand, the ground in the neighbourhood of Wellington, during an earthquake in 1855, was raised several feet. But these sudden changes are not always permanent. In 1835, a considerable extent on the western shore of South America rose a yard or more; but after a few months the ground sank again to its former level.

But these sudden alterations are of little moment compared with the tranquil movements of elevation and depression that are always going on. Observations carried on for more than a century show that the south of the Scandinavian peninsula is sinking; in the towns of Ystadt and Malmö whole streets have been abandoned to the sea. The northern part of the peninsula, on the contrary, is rising from two to three feet in a century. A similar movement of elevation is going on in Spitzbergen, Northern Siberia, Greenland, the whole western coast of South America, Japan, Asia Minor, &c.

165. **Raised Beaches.**—We see in many places on our own coasts flat terraces at a little distance above the level of the sea; and such a terrace has often at its landward margin a range of cliffs which bear evidence that the waves once dashed against them, as they now do against their present rocky border. We have here a visible proof that the ground has been pushed up several feet from below.

166. **Submerged Forests** afford a striking proof of subsidence. In the south of Devonshire, remains of a submerged forest are visible under five fathoms of water; and on the coast near Lincoln, low-water exposes stumps of trees protruding through a deposit of peat. From these and other facts, it is believed that the British Islands and the west of Europe generally must have subsided at least seventy feet since these trees were alive. But nowhere are there marks of such extensive subsidence as in the southern oceans, where many coral reefs and islands speak of the submergence of the foundations on which they were built (see par. 139).

167. **Repeated Alternations of Level.**—The sedimentary strata of the earth's crust everywhere bear evidence that these sinkings and risings have been going on since the beginning of geologic time. Nor has the movement been always in the same direction. The same portions have been repeatedly submerged, and as often upheaved. This is most strikingly seen in the 'Coal Measures,' as they are called. In the same 'field' there are often several seams of coal one above another, with sedimentary strata between. Now, from what was said above as to the origin of coal, it is clear that each seam bespeaks an oscillation of the level—a submergence and an upheaval.

168. **Causes of Upheaval and Subsidence.**—Some have maintained that these changes of level are due to the water, and not to the land—it is not the land that has risen, but the sea that has sunk. To refute this theory, we have only to look at Scandinavia. A rise of the sea-level would submerge the streets of Malmö; but from the very nature of water, if it rose at Malmö, it must rise at Tornea, and yet it there appears to sink. The most probable theory is, that the upheavals and subsidences of the ground arise from the gradual shrinking of the earth as it cools. The warm interior is losing heat faster than the comparatively cold exterior; and this causes the core to shrink away from the crust. But owing to its curved form, the crust cannot follow the core except by bending downwards at one place and upwards at another. In short, it is thrown into puckers like the rind of a shrivelled apple. In this way a continent may sink below the level of the waters, and an adjoining part of the sea-bottom be thrust up into the air. In this way also it has been brought about that beds of rock are seldom horizontal, but incline or dip in various directions; and where the bendings have been abrupt, they bear marks of having been crushed, twisted, and dislocated. Mountain-ranges may thus be regarded as simply corrugations produced by the shrinking of the earth's crust.

THE SEA.

169. **Composition of Sea-water.**—In every hundred parts of sea-water there are three and a half parts of solid matter in a state of solution. This solid matter is made up of a variety of salts; but four-fifths of the whole consists of common salt (chloride of sodium). The other

ingredients are chloride of magnesium, chloride of potassium, bromide of magnesium, sulphate of magnesia, sulphate of lime, carbonate of lime, with traces of silica, iodine, and ammonia. It is chiefly to the chloride and bromide of magnesium that the peculiar bitterness of sea-water is owing.

It has been made a question, *whence the sea got its saltness.* But in this there is no mystery. Salt is one of the substances that make up the globe, just as quartz is; and when the water began to condense from its original steam, and to gather together into the hollows, it would of course carry a large share of such a soluble substance as salt along with it. This original saltness must have been on the increase all along; for the water that falls from the clouds is continually dissolving the soluble parts of the solid earth and carrying them to the sea; and as evaporation brings none of this mineral matter back again, it must accumulate there.

170. **Why there is little Lime or Silica in Sea-water.**—There is little chloride of sodium now remaining in the superficial strata of the earth, and the chief substance now carried down in solution by rivers is carbonate of lime. Yet there is exceedingly little of this salt to be found in sea-water. The mystery ceases when we think of the countless marine organisms that are constantly using it up to form their shells and skeletons (see par. 137). From the same cause, the quantity of silica is comparatively small.

171. **Depth and Form of Sea-bottom.**—Much has been done in recent years to make us acquainted with the depths of the ocean. It is only of late that deep-sea sounding has been brought to perfection. A heavy weight attached to a fine line (or still better, to a piano wire) is let rapidly down; the weight, on touching the

bottom, detaches itself from the line, leaving only a tube which had been forced into the soil, and which brings up a portion, revealing its nature. In this way, depths of thousands of fathoms are measured with reliable accuracy. The greatest depth hitherto found in the Atlantic is 23,400 feet, or about four and a half miles; one sounding in the Pacific gave a depth of 27,900 feet, or more than five miles. The depths of 40,000 and 50,000 feet (nine miles) at one time reported, have been proved to be erroneous.

The bottom of the sea is not the exact counterpart of the surface of the land. There are great inequalities of level, but the changes are less abrupt. In one place there are flat tracts or plains at different levels; in another there are deep depressions; in a third are ridges rising sometimes to the surface or near it, and forming islands or sunken reefs. In most cases the ocean grows shallower towards the land. The seas around the British Islands, including the North Sea and the English Channel, scarcely exceed 300 feet in depth; an upheaval of 100 fathoms would convert into dry land an area equal to three or four times the United Kingdom.

172. **The Atlantic.**—The floor of the Atlantic is almost as well known as the geography of the adjoining continents. For 200 miles off the west of Ireland the water is shallow, but gradually deepening; then there is a more rapid descent (but not more than 1 in 25) to a vast undulating plain, which stretches westwards for a thousand miles to within 300 miles of Newfoundland; after that, the water gradually shallows towards the American coast. The average depth of the low plateau (called the 'Telegraph Plateau') is between 1000 and 2000 fathoms. Along the middle of the Atlantic, both north and south, there runs a zigzag ridge everywhere

of less than 2000 fathoms, and having deeper basins on both sides of it. Immediately north of the Virgin Islands is a remarkable depression, where a sounding of 3900 fathoms was obtained. The island of Bermuda rises abruptly from a bottom 2500 fathoms deep.

173. **The Pacific and Polar Seas.**—In the tracts hitherto sounded in the Pacific, the prevailing depths are from 1500 to 3000 fathoms. The greatest obtained (4575 and 4650 fathoms) were between New Guinea and Japan. The Polar Seas are comparatively shallow. Still more so are the smaller inland seas, the Baltic, Adriatic, Black, Yellow, &c. seas. The Mediterranean is deepest in its western basin, where the prevailing soundings are from 500 to 1000 fathoms.

The mean depth of the ocean is 2000 fathoms; and depths over 4000 are exceptional.

MOVEMENTS OF THE OCEAN.

174. **Only One Ocean.**—Rightly to understand the movements of the ocean, we must have a clear idea of the ocean as a whole. Turn the terrestrial globe till London is towards you, and step back till the eye takes in the

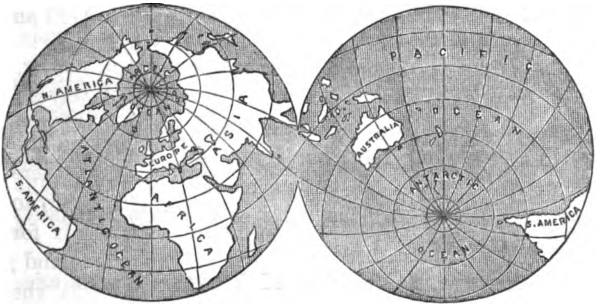


Fig. 29.—Hemispheres on the Plane of the Horizon of London.

half of the surface, keeping London in the centre; you will see nearly all the land on the globe—all but $\frac{1}{17}$th part. Next turn the other side of the globe towards you, making New Zealand the centre of the hemisphere you look at, and you will now see little else but water. This water hemisphere is the one ocean on the globe; and the Atlantic with the Arctic Ocean, and the North Pacific, are only bays of it extending into the north. When, therefore, we speak of the Indian Ocean or the Pacific, we must learn to think of them as parts of one great whole.

The waters of the ocean are never at rest; but their complex movements may be reduced to three—Tides, Waves, and Currents. The Tides fall to be considered at an advanced stage of the subject; we have here to notice Waves and Currents.

175. **Waves.**—In currents, the water travels or is transferred from one place to another; the movement is one of *translation*. In waves, the particles of water move up and down, or sway to and fro, without materially changing place—a movement of *oscillation*. A wave indeed seems to advance, but it is the *form* that travels, not the substance. There is a transmission not of matter, but of *energy*. Watch a cork on the surface of waves; it remains steady over the same part of the bottom. Stretch a rope along the ground, and shake one end up and down; a series of curves resembling waves runs along from end to end, the parts of the rope remaining over the same spot.

176. **Cause and Velocity of Waves.**—Waves arise from various causes, but the most usual is the disturbing force of wind. If you blow on the surface of a trough of water, you throw it into little ridges and hollows which travel on beyond the seat of the impulse till they are

arrested by the sides. In everything but size these ripples are identical with the billows of the Atlantic. It requires a large extent of water, and considerable depth, for the wind to have its full effect. Waves are sometimes seen as high as 40 feet from crest to trough, but this is believed to be the limit. The velocity of waves depends upon their length—that is, the distance between two crests, and the depth of the water. Thus a wave 1000 feet long and in water 10 feet deep, travels 12 miles an hour; in water 100 feet deep, the same length of wave travels 36 miles; and in water 1000 feet, 49 miles. With a wave 10,000 feet long, the rates in the same depths are 12, 39, and 115.

177. **Breakers and their Effects.**—When the water becomes shallow, so that the bottom interferes with the oscillation, the base of the wave is retarded, and the top bends forward and *breaks.* The force of heavy waves against an opposing object is enormous—a pressure of several thousand pounds on the square foot. Blocks of 800 tons have been displaced, and smaller ones of from 20 to 40 tons have been transported bodily for many feet.

The effect of this great natural force is to wear away the cliffs that form the sea-margin. On a rocky coast there are often to be seen solitary crags or sea-stacks, standing out of the water. These consist of the harder masses of the strata, that have longer resisted the action of the waves, and now serve as marks to show where the line of the cliffs once was. The destructive power of the water itself is greatly increased by the stones and sand which the waves upheave and dash against the base of the cliffs. The cliffs become undermined, and huge masses from time to time topple down. This debris is then tossed about and reduced to pebbles and sand.

You may watch the grinding process in any bay on a rocky coast. Each retreating wave draws down the shelving shore tons of pebbles, which the next advancing wave hurls back, to be again dragged down; and so on without ceasing. The pebbles are merely the remnants of the angular stones that fall from the cliffs. The rest has been ground off in the form of sand and impalpable powder; and this finer matter is carried out in a state of suspension, and deposited at some distance from the shore to form strata of future dry land.

Some rocks are so compact and hard that the waste is imperceptible; where the cliffs are of friable material, as on the English coast between Flamborough Head and the mouth of the Humber, the coast is receding at the rate of a yard yearly.

178. **Currents.**—Currents are veritable 'rivers in the ocean.' Over a tract of definite breadth the water at and near the surface is coursing along in a definite direction; and a vessel coming into such a stream without knowing of it, is carried unawares out of its course. Some of these currents are well marked and permanent; others change their position or direction; and it would be difficult, perhaps, to find any part of the ocean where the water is not setting in some direction or other. These superficial movements form what is called the Horizontal Circulation of the ocean. But there are deeper flows in which the waters are held to rise and sink, forming a Vertical Circulation.

The horizontal movements are mainly (according to some, entirely) owing to prevailing winds, which drive the surface-water before them. Hence the name of *drift currents.* The vertical circulation is believed to originate mainly in differences of temperature in different parts of the ocean.

179. **Circulation caused by Differences of Temperature.**—The powerful sun of the Tropics heats and expands the waters of the ocean to a considerable depth; while the cold of the poles renders the water there dense and heavy. The balance of pressure is thus destroyed; the heavier polar water sinks down and flows in below the waters lying nearer the equator, while these lighter waters flow over towards the poles to restore the level. Such is the theory of what we should expect to take place; and, so far at least as the flow of the cold water below is concerned, observation seems to confirm the theory. Wherever the ocean is open through its whole depth to the polar seas, there a stratum of ice-cold water is found at the bottom, even under the equator; and this must necessarily come from the polar regions. As the oceans are most open towards the South Polar Sea, it is chiefly from it that the cold bottom currents come; so that they look like tongues shot out by the lower strata of the Antarctic Ocean. The return flow of warm water towards the poles is more difficult to trace, as it is interfered with and disguised by the wind currents.

180. **This Theory disputed.**—In fact, some deny that differences of temperature have any sensible effect on the circulation of the waters. They hold that all the currents in the upper strata of the ocean can be traced directly or indirectly to the impulse of winds; and they account for the flow of glacial waters from the antarctic seas along the deeper channels of the oceans, by assuming that there is a greater amount of evaporation in the northern hemisphere than in the southern; that this excess of vapour is carried in the upper strata of the atmosphere, and precipitated in the southern seas; and that the deep current from south to north sets in to restore the equilibrium. The objection to this theory

upon the eastern coasts of the continents. A branch turns northwards and circles round the closed end of the Pacific, tending to curl back to the North American coast from its excess of initial velocity; and in the Atlantic, following a corresponding course, the Gulf Stream bathes the shores of Northern Europe, and a branch of it forces its way into the Arctic basin, and battling against the palæocrystic ice, keeps imperfectly open the water-way by which Nordenskjöld hopes to work his course to Behring's Straits. The southern deflections are practically lost, being to a great extent, though not entirely, dissipated in the great westerly current of the southern anti-trades.'

182. **Current of the Atlantic.**—The equatorial current in the Atlantic, with its deflections and secondary currents, being the best known, may be taken more in detail as typical of the whole set of phenomena. It sets from the west coast of Africa towards the east coast of Brazil, and is owing to the trade-winds (see par. 250), which push the waters of the Atlantic westwards. The depth of such a drift-current is not great—not exceeding 50 fathoms—and the velocity is less than a mile an hour.

183. **Indraught-currents.**—But here we must note an indirect effect of this action of the wind. The waters being blown away from the African coast, a depression is caused, and to fill it up, two *indraught-currents* set in, the one from the north along the coast of Portugal and Morocco, the other from the Cape of Good Hope along the west coast of Africa; and both these currents, it may be added, are aided by winds blowing in the same direction.

184. **Equatorial Current divides.**—When the equatorial current itself reaches the coast of Brazil, it divides

into two branches. One proceeds southward, turning gradually eastward, and a part of it curling fairly round, flows northward along the African coast until it falls in with the northern indraught formerly spoken of, and thus makes the complete circuit. The rest of this branch finds its way into the Southern Ocean, and merges in the easterly drift caused by the anti-trades. The other and much larger branch of the equatorial current is deflected northward into the Caribbean Sea and the Gulf of Mexico. The water thus driven into this pent-up sea now rushes with accumulated force through the strait or gulf between Florida and the Bahamas, and forms the famous Gulf Stream.

185. **The Gulf Stream.**—The Gulf Stream, after issuing from the Florida Strait, proceeds at first northward, parallel to the American coast; but after coming to Cape Hatteras, it turns gradually eastward, passing over the southern extremity of the Bank of Newfoundland, and all the while expanding in breadth and becoming shallower. The temperature of the stream when it starts is from 83° in summer to 77° in winter, and even after travelling 3000 miles to the north, as high as the Banks, there is a difference in a winter day between its water and that of the surrounding ocean of 20° to 30°. Along its whole course a cold polar current underlies it; and this polar current comes in between the western border of the stream and the coasts of Florida, Georgia, and the Carolinas, the line of separation between the two being so abrupt that it is known as the 'cold wall.' The velocity of the stream at its outset is from 50 to 60 miles a day; but this velocity becomes greatly reduced as it proceeds.

186. It has usually been held that the Gulf Stream extends across the Atlantic to the shores of Northern

Europe, and is the cause of the mild and moist climate enjoyed by the western parts of that continent. The opinion, however, is beginning to prevail that, as a distinct current, the Gulf Stream ceases in the middle of the North Atlantic, its waters being by this time thinned out to a mere film, and its original velocity and distinctive heat having been dissipated. That warm waters from tropical seas are brought to the coasts of Britain, and even into the Polar Seas beyond, is proved by drift-wood, seeds, and fruits from the West Indies being frequently cast ashore on the Hebrides, the north of Norway, and Spitzbergen. But this is accounted for by the general flow of the surface-water towards the poles, forming part of the vertical oceanic circulation; a flow which receives an eastward deflection as it proceeds northward. This general set of the surface-water is further promoted by the prevalence of south-westerly winds, which maintain a pretty constant north-east drift over the whole surface of the north-eastern portion of the Atlantic. In this way, although the Gulf Stream may have lost its original impetus, a large portion of the superheated water which it brings into the centre of the Atlantic must be carried to the shores of Europe and into the Arctic Sea.

187. **The Labrador Current.**—While the climate of the west of Europe is thus rendered mild by having its shores washed by waters from warm seas, and by the moist and south-westerly winds that predominate, the opposite coast of America is greatly depressed by a current from the Greenland seas which flows southwards along the shores of Labrador, carrying with it fields of polar ice and icebergs, and accompanied by dry and piercing winds from the north.

188. **The Sargasso Sea.**—Part of the waters of the

Gulf Stream in the region of the Azores becomes deflected southward until it falls in again with the equatorial current and turns westward. In the centre of the whirl thus produced there is a tract of still water covered with floating seaweed (*Sargassum bacciferum*), and called the Sargasso (grassy) Sea.

189. **Currents of the Pacific.**—Part of the equatorial current, on reaching the Indian Archipelago, is deflected northward along the coast of China, and then, under the name of the *Japan Current*, curves eastward towards the coast of North America, where it turns southwards to feed the equatorial current, and thus renew its circuit. Another part of the western drift, impinging on Australia, turns southwards as the New South Wales Current, and passing New Zealand, merges in the anti-trades' drift of the southern seas.

190. **Currents of the Indian Ocean.**—The southern part of the equatorial current, when near the African coast, turns southward, and rushing through between Madagascar and the continent, is known as the Mozambique Current. North of the equator, the marine currents follow the guidance of the monsoons (see par. 252), and therefore change their directions with the seasons.

191. **Inland Seas.**—Inland seas have of course their local drift-currents depending upon the prevailing winds. But besides this, a circulation is kept up between their waters and those of the oceans, depending upon the relation that exists in each between the evaporation and the supply from rivers and rainfall. In the Mediterranean, the evaporation is in excess of the influx of water from rivers. There is therefore an eastward flow from the Atlantic through the Straits of Gibraltar to restore the level. At the same time there is an under-current, though to a smaller amount,

running the other way, owing to the greater saltness and heaviness of the Mediterranean water. In the Black Sea, the river water and rainfall are in excess of evaporation, and the superfluous waters form a surface-current through the Bosphorus, while there is a counter deep current of salter water from the Ægean. The Red Sea has practically neither rainfall nor rivers, and the evaporation would lower the level 20 feet in a year. If there were only an influx from the Indian Ocean through the Straits of Babelmandeb to keep the sea full, the water would in time become brine; there is therefore a counter-current which prevents the salinity from becoming excessive. During part of the year, the surface-current is from south to north; for the rest of the year, it is from north to south, according to the prevailing wind. The many rivers falling into the Baltic keep it overflowing into the North Sea, and it is prevented from becoming a fresh-water lake by a counter under-current from the same sea.

TEMPERATURE OF THE SEA.

192. **Band of Uniform Temperature.**—'The shallow stratum of water forming the ocean,' says Sir Wyville Thomson, 'is very definitely split up into two layers, which, so far as all questions concerning ocean movements and the distribution of temperature is concerned, are under very different conditions. At a depth varying in different parts of the world, but averaging perhaps 500 fathoms, we arrive at a layer of water of a temperature of 40° F.; and this may be regarded as a kind of neutral band separating the two layers. Above this band the temperature varies greatly over different areas, the isothermobathic lines being sometimes tolerably equally distributed, and at other times crowding

together towards the surface; while beneath it the temperature almost universally sinks very slowly, and with increasing slowness, to a minimum at the bottom.'

This is true, however, only of the ocean where it is

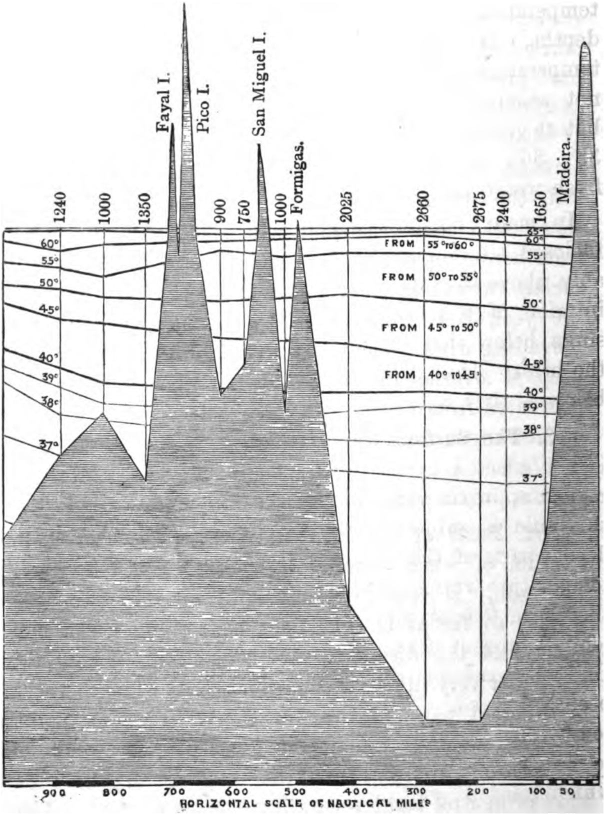


Fig. 30.—Section of the Atlantic, from the Azores to Madeira.
Showing soundings (in fathoms) and isothermal lines obtained in H.M.S. *Challenger* (Captain G. S. Nares), 1873.

open to the influx of the cold currents from the poles.

In the Mediterranean, for example, the surface temperature ranges from 80° in summer to 54° or 55° in winter. But this excess of summer heating does not extend beyond a depth of 100 fathoms: below this, the temperature of 54° or 55° is maintained constantly at all depths. In the Atlantic, in the same latitude, the temperature of the upper stratum of 100 fathoms does not essentially differ from that in the Mediterranean; but at greater depths, the temperature sinks to 49°, 40°, 38°, 36°, and in some places to the freezing-point of fresh water, and even below it (29·6°).

In many parts of the open ocean there are basins inclosed all round by submarine ridges rising considerably above the level of the bottom. However deep the interior of the basin may be, the temperature never sinks below that of the stratum at the lowest level of the brim. The rocky barrier shuts out the colder strata below as they well northwards along the bottom.

193. **The Surface Temperature of the Sea,** where it is not affected by currents from a colder or a warmer region, approximates to that of the air above it. But this rule is subject to great modifications. Over the deeper parts of the equatorial Atlantic, the surface mean temperature varies from 75° to 80°. In the Red Sea, the mean temperature is from 77·0° to 81·5°; but a temperature of 94·0° was once recorded near Aden. On the coast of Siam, a temperature of 91·0° has been observed. The cause of the comparatively low temperature over the deeper parts of the Atlantic is to be looked for in the glacial waters at the bottom, which must be continually rising up to supply the waste caused by evaporation and by the equatorial drift. It is remarkable that below the upper 60 or 80 fathoms directly affected by the solar heat, all the water in the

North Atlantic as far as lat. 40° is warmer than at the same depth under the equator.

194. **Density of the Ocean.**—The average specific gravity of sea-water is 1·02655; but exceptional circumstances cause considerable variations. Ships and other floating objects are thus slightly more buoyant (*i.e.*, sink less deep) in the sea than in fresh water.

195. **Influence of the Sea on Climate.**—The sea, in virtue of its circulation, mitigates the extremes of heat and cold. The currents above described carry the heat of the tropics into temperate and polar regions, and the cold of the poles into the tropics. This is best exemplified in the North Atlantic. The shores of the British Islands, of Norway, and even Spitzbergen, are bathed with waters that have travelled from the West Indies, as is proved by branches of trees and other products that they bring along with them; and the genial temperature of these waters makes itself felt over the adjoining lands through its influence on the atmosphere. On the opposite side of the Atlantic, a cold current from Davis Strait flows along the coasts as far as Florida, and produces the contrary effect. The mean annual temperature of the north of Ireland in N. lat. 55°, is 50° F.; to find the same temperature in America, we must go as far south as near New York in N. lat. 41°. The isothermal of 40° F. passes Quebec in N. lat. 46·48°, through Newfoundland, and runs north-east to the coast of Norway in N. lat. 66°. The Japan Current affects the climate of Alaska and British Columbia in much the same way as the Gulf Stream affects that of Northern Europe. The warm waters deflected southwards from the equatorial current (see pars. 184 and 189) into the Antarctic Ocean, are believed, along with the prevailing west and north-west winds, to check the indefinite extension

of the ice-cap that covers the South Polar lands (see par. 268).

THE ATMOSPHERE.

196. **Elasticity of the Atmosphere.**—The atmosphere (from Gr. *atmos*, smoke or vapour, and *sphaira*, a globe) is as much a part of the globe as the ocean is. It forms the uppermost stratum, as it were, and partakes of the annual and diurnal motions. The matter of which it is composed is highly elastic, as is distinctly felt in using a pop-gun. The lower strata are consequently denser than the higher; just as is the case when you make a pile of light fluffy matter like wool or straw. It results from this that at the top of Mont Blanc, only three miles above sea-level, half the weight of the atmosphere is left below, and a given space, say a cubic foot, contains only half the mass of air that it contains at sea-level. The rarefaction goes on increasing in geometrical ratio with the ascent, until the expansive force becomes so weak that it is balanced by the weight of the particles. At what height this takes place has not been exactly determined. A height of 7½ miles has been reached in a balloon, and there the air was so rare that it was hardly possible to breathe; and a pigeon dropped from the car, fell downwards, like a stone in water, till it reached air dense enough to resist its wings.

197. **Height of the Atmosphere.**—After the sun sets, his rays continue to strike the upper part of the atmosphere, and the particles of the air reflect or send some of the rays earthwards. It is these faint rays that constitute twilight. Now, this twilight region is observed to terminate at a height of about 50 miles, and it is inferred that beyond this the air is too thin to reflect

any light. But that the atmosphere extends far above this height is clear from the appearance of meteors. Meteors or shooting-stars are dark bodies careering through space, and that burst into light when they chance to enter our atmosphere. Their velocity is such that the friction against the air-particles heats them to whiteness. Now, it has been found by calculation that meteors come into view usually at a height of 70 miles, but occasionally they are observed as high as 200 miles. There must therefore be air at this height, however rare.

198. **Weight of the Atmosphere.**—The substance of the air is invisible, but we feel it resisting us when we move a flat surface rapidly against it; and when it itself is in motion, we feel it as wind. Air has weight like everything material. A cubic foot of air at the earth's surface weighs rather more than an ounce. The weight of the whole atmosphere is such that it presses with a force of 15 lbs. (more nearly 14¾) on every square inch. That we are quite insensible of this is owing to the pressure being the same on all sides.

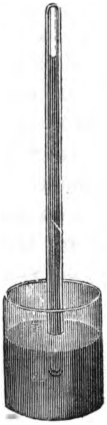


Fig. 31.
Torricelli's
Experiment.

199. **How Measured.**—The amount of the pressure of the atmosphere is thus determined: Take a glass tube not less than 33 inches long, and open at one end; fill it with mercury; close the open end firmly with the thumb, invert the tube, and place it vertically with the end immersed in a cistern of mercury. When the thumb is removed, the mercury in the tube sinks, however long the tube is, till it stands about 30 inches above the level of the mercury in the basin. The space above the mercury in the tube is a vacuum. The whole

weight of this column in the tube presses on the mercury in the basin, and according to the law of hydrostatics, that pressure is propagated in all directions, and would force up the substance of the mercury were it not balanced by an equal pressure downwards. That pressure can come only from the atmosphere. That it is so was proved by Pascal carrying the apparatus to the top of a mountain; the height of the column was found to become less and less, the greater the elevation, because more and more of the atmosphere was left below.

If the area of the tube is a square inch, the column of mercury weighs about 15 lbs., which must therefore be the weight of a column of air having a square inch base, and reaching to the top of the atmosphere. If water were used in the experiment instead of mercury, the column would stand at the height of about 34 feet, the weight of water being nearly 14 times less than that of mercury. It is easy to find the weight of the whole atmosphere in pounds by multiplying the number of square inches on the surface of the globe by 15; it has been calculated to amount to 77,670,000,000,000,000 lbs. An ocean of mercury of the uniform depth of 30 inches, or one of water 34 feet deep, covering the face of the globe, would have the same weight.

200. **The Barometer.**—In the experiment of Torricelli with the mercury and tube (see par. 199), we have the essential principle of the barometer (from two Greek words signifying weight and measure); and when the apparatus is fixed in a frame, and provided with a scale to mark the height of the column, it forms what is called the *cistern* barometer, which is still the best where accuracy is required.

201. **The Aneroid Barometer.**—In this form of barometer no liquid is employed, and hence the name

(Gr. *a* priv., *neros*, wet). A flat circular metal box is nearly exhausted of air, and soldered air-tight. The external air causes the flat sides of the box to bend inwards more or less, according to varying pressure of the atmosphere, and a system of levers connected with the sides, to make an index hand move over a graduated scale. The scale is graduated to represent the inches of the mercurial barometer, and the results correspond with wonderful accuracy; but as the instrument is liable to change, it is necessary to make frequent comparisons with the ordinary barometer.

DISTRIBUTION OF PRESSURE.

202. The pressure of the atmosphere varies considerably from place to place, and from time to time, and these variations are the chief cause of all fluctuations of wind and weather. A knowledge, therefore, of the distribution of pressure over the globe, and the laws of the changes, as indicated by the barometer, is the basis of meteorology. Fluctuations of pressure arise from two causes—differences of temperature, and differences in the quantity of water vapour.

(1) **Pressure affected by Temperature.**—When a portion of the earth's surface is heated more than the surrounding regions, the air expands, becomes lighter, and flows over into those regions. The column of air over the heated area thus loses part of its mass, and has less pressure. The opposite effect is produced by cold. Over a cold region the air contracts and sinks down, and additional air flows in above, thus increasing the weight of the column.

(2) **Pressure affected by Vapour.**—Vapour has less specific gravity than air; a mixture of air and vapour

therefore weighs less than the same bulk of dry air. When the air, then, contains a deal of vapour, the weight of the whole column—in other words, the barometric pressure—must be less than when the air is comparatively dry.

203. **The Movements thus caused—Cyclones.**—Whenever a difference of pressure is thus established between two atmospheric columns from one or both of these causes, the column of high pressure must flow out at the base towards the region of low pressure. A current of air flowing into an area of low pressure, does not proceed straight to the centre, but (owing to a cause explained in par. 255) in a spiral direction, circling round and round it, and always getting nearer. On account of this circling of the air within it, an area of low pressure, or to express it shortly, a *depression*, is called a *Cyclone*, and the movement, a *cyclonic* movement. An area of high pressure is called in contrast an *anti-cyclone*. It is within the areas of depression that storms and foul weather occur; within an anti-cyclone, calm weather or gentle breezes prevail.

204. **Isobars.**—The distribution of atmospheric pressure is best exhibited by means of *isobarometric charts;* that is, charts on which lines, called *isobars*, are drawn through all places where the height of the barometer is the same. Such a chart may represent the mean pressure for the year, or the mean for a portion of the year, such as a particular month; or the readings of the barometer at a specified moment, such as the beginning or middle of a storm. A complete series of charts representing by isobars the mean pressure over the globe for the year, and for every separate month, has been constructed by Mr Alexander Buchan, Secretary to the Scottish Meteorological Society.

Regarding the mean for the whole year, the result may be thus briefly stated: A broad belt of low pressure extends round the equatorial regions of the globe; on each side of this there is a parallel tract of high pressure; and about each pole lies a region of low pressure.

205. **Annual Variation.**—But this state of things is greatly modified by the seasons. These changes, known as the *annual variation* of the barometer, follow the march of the sun from one side of the equator to the other. The greater power of the sun in the northern hemisphere in summer rarefies the air, and causes a transference of a part of it into the colder southern regions, thus diminishing the pressure in the former. The presence of a greater proportion of vapour acts in the same direction, owing to vapour having less specific gravity than dry air. As a rule, then, the atmospheric pressure is least in the summer, and greatest in the winter, in each hemisphere.

206. **Local Differences.**—But this annual fluctuation is subject to great local differences and anomalies. Thus, in Siberia, the pressure is $\frac{9}{10}$ths of an inch less in July than in January. The great heat of Siberia in summer causes the air to expand and flow away in all directions. In winter, on the other hand, the great cold and small rainfall of that region cause high pressures to prevail. In Iceland and Orkney, again, the reverse of all this holds: the pressure is least in winter, and greatest in summer. The summer temperature of the North Atlantic, in which these islands are situated, is cool as compared with the heated continents that inclose it, hence there is an overflow from these regions into the basin of the North Atlantic, and therefore increased pressure; while in winter the temperature there is

comparatively high, causing an overflow of air towards the adjoining countries and a diminished pressure.

207. **The Barometer as a Weather-glass.**—As wind and weather depend so much upon the fluctuations of atmospheric pressure, the barometer which indicates those fluctuations has got the name of the weather-glass. At certain points of the scale, the makers of common barometers have marked the words 'Rain,' 'Change,' 'Fair,' &c.; but this is very misleading. Along with the actual height of the barometer at the particular place, we ought to take account of its height in the surrounding regions, the amount of vapour in the air, and the temperature. Generally speaking, a falling barometer indicates rain; a rising barometer, fair weather. A steady barometer foretells a continuance of the weather at the time; when low, this is generally broken or bad; when high, fair. A sudden fall usually precedes a storm, the violence of which is in proportion to the suddenness of the fall. An unsteady barometer shows an unsettled state of weather; gradual changes, the approach of some permanent condition of it. The variations must also be interpreted with reference to the prevailing wind, each different wind having some peculiar rules.

208. **Corrections of the Barometer.**—In order that two or more barometric observations may be compared with one another, they require two corrections—for Temperature and for Height.

(1) Mercury expands $\frac{1}{9990}$ of its bulk for every degree of F. So that, if the barometer stands at 30 inches when the temperature is 32°, it will stand higher by about $\frac{1}{10}$ inch when the temperature is 65°, although the pressure is the same in both cases. Every observation made with the temperature above 32° has to be reduced by so much to bring it to the standard of 32°.

(2) A barometer at the top of a tower will of course give lower readings than one at the foot. For comparison, all observations are reduced to the sea-level. The law connecting the diminution of pressure with height is rather complicated; but tables have been calculated, giving the corrections to be made according to elevation and temperature.

209. **Measurement of Heights by the Barometer.**—The fact that the barometer falls as we ascend, and that by an ascertainable law, enables us to use it as an instrument for measuring heights. Two observations are taken at the same time, one at the foot of a mountain, the other at the top. At each place the height of the barometer, and the temperature both of the air and the barometer itself, require to be noted. From these data, by means of logarithms and a somewhat complex formula, the differences of level of the two stations can be calculated. A near approximation may be made to the exact measurement by means of the table of corrections for height. Within 1000 feet of sea-level the difference in the mercurial column is roughly $\frac{1}{10}$th of an inch for every 100 feet.

COMPOSITION OF THE ATMOSPHERE.

210. The atmosphere is a mixture of several gases, but the great bulk of it ($\frac{29}{30}$ths of the whole) is made up of two—oxygen and nitrogen (see par. 102). The nitrogen is much the more abundant of the two, being to the oxygen as 4 to 1 by measure, and as 10 to 3 by weight (more exactly: in 100 pints of pure dry air, 79 are nitrogen and 21 oxygen; in 100 ounces, 77 are nitrogen and 23 oxygen). The two gases are undistinguishable by the eye; but they differ in properties as much as water and alcohol. Although the nitrogen is in greater

quantity, the oxygen is much the more important; it is the supporter of life and the indispensable agent in combustion, in putrefaction, and many other natural processes; while nitrogen serves chiefly to dilute the oxygen.

211. **Vapour.**—Of the other ingredients of the atmosphere, the vapour of water is the most important. The quantity present varies greatly; in a hot moist climate, the thirtieth part of the atmosphere may be vapour; in a dry region and in extreme cold anywhere, there is very little (see par. 225).

212. **Carbonic Acid.**—Next in importance is carbonic acid. It is produced by the breathing of animals, by the decay of organic matter, and by combustion. The proportion in the air in ordinary circumstances is 1 part in 2400 of bulk; and when thus diluted, it does no harm; but as much as 1 in 300 is very hurtful. Hence the mischief of crowded rooms. An excess of carbonic acid in the atmosphere generally is provided against by nature in the fact that it is absorbed by living plants (see par. 109).

213. **Ammonia,** the gas which produces the pungent smell when feathers or wool is burnt, exists in the air in very small quantity—about 1 part in a million. It arises from the putrefaction of animal and vegetable matter. Ammonia is an essential ingredient in the food of plants, although the quantity is small in proportion to the carbon. Cultivated plants get part of their supply from manure that is put into the soil, but the greater part is derived from the atmosphere. It is either imbibed directly by the leaves, or carried down by rain into the soil and then absorbed by the roots. Wild plants depend on the atmosphere solely. It thus appears that the air is the main source of sustenance for plants,

and if for plants, then also for animals which live on plants. It is thus for us the *vital* air in more senses than one.

214. **Ozone** is the substance that causes the peculiar smell given out by an electric machine. It is simply oxygen the atoms of which are grouped in some peculiar way so as to have exceedingly active properties. It purifies the air by decomposing decaying animal and vegetable matter. There is less ozone in the air of towns than in the country. It is particularly abundant in sea-breezes and in elevated situations.

215. **Dust.**—There is perhaps no substance on the earth of which some emanation does not exist in the air. Besides the gases above mentioned, and others of less importance, there are multitudes of solid particles floating in suspension. When a beam of light is allowed to enter a darkened room, its course is made visible by the thousands of *motes* it encounters, which reflect the light. Without the motes the beam itself would be invisible. Besides small fragments of dead matter, this floating dust contains the germs of low forms of living organisms, which are ready to come to life when they find a fitting lodgment. It is believed that many diseases are thus propagated. Recent researches make it appear that the deposition of moisture in the form of fog and clouds is largely dependent on the presence of solid particles floating in the air.

216. **The Atmosphere not a Chemical Compound—Gaseous Diffusion.**—The gases that compose the atmosphere are not chemically combined; they are only mixed. Into the proof of this we need not enter. But a difficulty here presents itself. Oxygen is sensibly heavier than nitrogen, and carbonic acid much heavier than either. Why, then, does not the nitrogen float on

the top of the oxygen like oil on water, and the carbonic acid find its place below both? This is owing to the *diffusive* force of gases. A gas is made up of molecules which keep one another at a distance by a repulsive force. From the fact that any gas can be compressed into a very small fraction of its ordinary bulk, we are sure that its particles are usually at a great distance from each other in comparison with their size. Now, suppose two flasks connected by a tube having a stop-cock, by which communication can be cut off, and suppose the one filled with nitrogen, and the other empty; on turning the stop-cock, part of the nitrogen will rush into the empty flask until it is equally spread over the whole space; for there is no stable balance of the repulsion if a particle is nearer its neighbour on one side than on the other. This uniform diffusion takes place almost instantaneously when the one flask is empty. But now, suppose both filled, the one with nitrogen, and the other with oxygen; when the communication is opened, each gas spreads itself uniformly through the whole space of both flasks, precisely as the nitrogen alone did, only in this case time is required. The gases mutually interpenetrate, and the molecules of the one retard the progress of those of the other, but do not otherwise affect the ultimate result. Each gas is independent, and distributes itself, and exerts its pressure precisely as if the other were not there. It is owing to this important principle that the proportion of oxygen to nitrogen is the same in all parts of the world and at all heights. The same law of uniform diffusion, and independence of the presence of other gases, holds with regard to the carbonic acid gas and the aqueous vapour existing in the atmosphere, although, in the case of aqueous vapour, its constant liability to condensation prevents its ever attaining to a state of actual uniformity.

DISTRIBUTION OF TEMPERATURE.

217. **Horizontal Distribution.**—The sun is the source of warmth on the surface of the globe; the internal heat of the earth itself makes its way so slowly to the outside, that it may be left out of account. The laws of radiant heat are stated in pars. 91, &c., and the learner should here rehearse them. Every one knows as a fact that the equatorial regions receive more heat than the rest of the globe. This arises from the position of the earth's axis with regard to the sun, which causes the sun to rise higher in the equatorial heavens, and shed his rays more directly downwards. The accompanying diagram will make the effect palpable (fig. 32).

The circle represents the globe, and the sun is supposed to be an immense way off to the right hand, with his rays coming in parallel lines towards the earth.

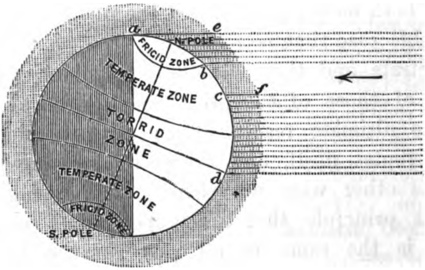


Fig. 32.

The axis of the earth is supposed to be in the position with regard to the sun that it holds at our midsummer. Now, if *ab* represent a strip of surface running north and south near the pole, and *cd* a strip of the same length near the equator, we see that *cd* receives nearly three times as many rays as *ab*. But this is not the only effect of obliqueness. The rays, on passing through the earth's atmosphere, lose part of their effect; and we can see that a slanting ray like *ea* must suffer more than a nearly perpendicular one like *fc*. The same causes explain the great daily difference between the power of the sun at mid-day and his power in the morning or evening.

218. The mean temperature of the equator is about 80°. If the whole earth were a perfectly smooth globe of one uniform kind of surface—that is, if it were all sea, or all one kind of level land, the temperature would decrease steadily from the equatorial amount, according to the latitude; but the variations of the surface cause many deviations.

219. **Effects of Elevation on Temperature.**—We have seen that as we descend below the surface of the earth, the temperature rises. The opposite effect follows when we ascend a mountain, or mount into the air in a balloon—the thermometer falls. The average fall is 1° of F. for every 300 feet of elevation. At first sight we might expect a rise instead of a fall, for, during the day at least, the sun is nearer to an elevated position than to a low. Several causes concur in producing the effect in question. (1) A chief cause is the increased rarity of the air. Although the air derives its heat chiefly from contact with the earth after the latter has been heated by the sun, it does absorb a portion of his rays directly; and it also catches a portion of the heat rays streaming off from the earth. It thus acts like a protective covering, mitigating the fierceness of the sun's rays, and retarding the escape of the heat already

received. Now, the thinner this covering, the less will be its effect in both ways. Were there no atmosphere, the heat of the sun would be fierce while it struck, but so rapid would be the loss by radiation, that the whole earth would be kept constantly below freezing; for it has to be remembered that the gain is only while the sun is shining, but the loss by radiation goes on day and night.

(2) This protective effect of the atmosphere is much greater when the air is charged with moisture (par. 95) than when it is dry. Now, the proportion of moisture decreases rapidly as we ascend, and therefore objects in high regions, where there is only thin air, and little or no vapour, are exposed naked, as it were, to the cold of the outer universe.

220. (3) **Effects of Isolation.**—On an elevated tableland like Tibet, the temperature is higher during the day and during summer than on an isolated peak at the same height. On the peak there is little extent of surface to evolve the heat of the sun's rays, and no objects to return the radiation.

221. (4) **Effects of Expansion.**—Currents of air are constantly ascending from the heated earth, and we might expect that the temperature of the higher regions would thus be equalised. But as the air ascends, it is relieved of pressure, expands, and falls in temperature, the motion of expansion being effected at the expense of a portion of its heat. Air heated to 80° has not ascended many thousand feet before it is at the freezing-point.

222. **Vertical Climates.**—Owing to the causes now assigned, by ascending a lofty mountain in the tropics, it is possible to encounter in succession all varieties of climate from tropical to polar.

223. Uses of the Thermometer.—The thermometer is an indispensable instrument in science and in many of the practical arts, as well as in daily life. Heat is popularly defined as the unknown cause of the sensation of warmth; but as to the comparative degrees of warmth in bodies, our sensations give us very vague and often wrong notions.* To the touch, the mantelpiece in a room feels cold, the table-cloth much less so. The truth is, that both are really in the same condition as to degrees of heat; but the one, owing to its greater conductivity (see pars. 85, 87), robs the hand of its heat more rapidly than the other. Hold one hand for a moment or two in hot water, and the other at the same time in water decidedly cold, and then grasp a stick at the temperature of the air with both; to the one hand the stick will feel cold, and to the other warm. The thermometer enables us to correct all this vagueness and inconsistency, and furnishes a sure and unvarying standard. By means of it the meteorologist can compare with exactness the climates of the several regions of the earth, and the smaller differences between adjacent localities. These determinations have a direct bearing on the art of agriculture, and on regulations regarding public health. In such arts, also, as horticulture and brewing, much often depends on minute differences of temperature which the senses are incapable of discriminating. More especially in the laboratory of the chemist is the use of the thermometer indispensable, as the actions of chemical affinity are often greatly modified by temperature.

---

* It is to be observed that the question here is not as to the *amount* of heat in bodies, but as to their *temperature*—that is, the *intensity* of their heat, which is shown by the degree of expansion it produces, and by the energy with which it is communicated to other bodies (see pars. 43, 77, 81, 83, 96). Two bodies are of the same temperature when neither communicates heat to the other when in contact.

EVAPORATION AND CONDENSATION.

224. **Evaporation.**—Take a towel, weigh it, dip it in clean water, and wring it out so that it will not drip. Now weigh it again, note the increase, and hang it up in the open air. In a few hours it will be dry, and its weight will be found to have returned to what it was at first. Here several ounces of water have disappeared. What has become of it? According to a popular expression, the water 'dries into' the substance from which it disappears. But if so, the weight of the towel would show it. It has not dried *into* the towel, but *out of* it and *into* the air, which has taken it up like a sponge. From seas, lakes, and rivers, and from every moist surface, water is thus rising silently and invisibly into the air, and this is *Evaporation* in the ordinary sense. Boiling is essentially evaporation; the difference being, that in boiling, the high temperature gives the vapour force enough to rise from the bottom in masses, displacing the water and the atmosphere, and then it is properly steam; while in ordinary evaporation, the vapour can only insinuate itself, molecule by molecule, between the molecules of the atmosphere.

225. **Evaporation ruled by Temperature.**—The amount of vapour that air can absorb depends upon its temperature. Suppose a glass jar filled with perfectly dry air and covered with a close lid, and that we could introduce into it a small shallow capsule of water suspended by a delicate spring balance. Let the temperature be 60° F. —that of a medium day. The evaporation would be at first rapid, but would gradually become slower—as would be shown by the diminishing weight of the capsule—

until at last it will altogether cease. The air is *saturated* (Lat., filled full), and can hold no more. If we could now suddenly raise the temperature of the whole apparatus to 80°, the evaporation would go on anew, and would again cease after a time, the air being a second time saturated; and it would be found that the loss of weight in the capsule would be now about twice as much as at the first saturation.

Properly speaking, it is the space that contains the vapour, and not the air. If the glass jar were a vacuum like the receiver of an air-pump, the same amount of vapour, neither more nor less, would rise into it at each of the two temperatures as before; with this difference, that in the vacuum it would rise and diffuse itself almost instantaneously, while the presence of air retards the diffusion.

226. **What makes a Drying Day.**—When the air is already nearly saturated, it can take up little more, and that slowly; when far below saturation, it is *thirsty*, and drinks up moisture with avidity wherever it can find it. Cold air contains little moisture even when saturated. When, therefore, air at the freezing-point is admitted into a house and heated artificially, say to 70°, it is rendered fiercely thirsty, and parches the skin and lungs of the inmates. In such cases there should be an evaporating pan to keep the air in a moderate condition of moistness.

A windy day has a greater power of drying than a still day, for this reason, that in calm air the film next the moist object is soon saturated, and the vapour makes its way outward slowly; whereas wind brushes the surface with constantly fresh portions of air.

227. **Evaporation produces cold.**—Wet the back of the hand and expose it to the air; as it dries, the skin

feels cold, especially if the hand is moved about. Take two tin cans of the same size, cover one of them with cotton cloth, and fill them with water of the temperature of the air. Now wet the covering, and allow both to stand in the free air. In a short time the covered can will be several degrees colder than the naked one. The explanation of these experiences is found in the latent heat absorbed by vapour (par. 96). From this cause it is dangerous to allow wet clothes to dry on the person; the evaporation robs the body too rapidly of its heat. Water may be evaporated so rapidly in a vacuum that the remainder freezes in the vessel. The evaporation of ether produces a still more intense cold.

228. **Hygrometers** are instruments for measuring the degree of humidity of the air. There are many contrivances for this purpose, but the most convenient is the *dry-and-wet-bulb thermometer.* It acts on the principle of the experiment with the two cans. Two common thermometers are fixed side by side. The bulb of one of them is covered with thin muslin, having a few threads of darning cotton passing into a small vessel of water. The muslin is thus kept wet by capillary attraction. The uncovered thermometer or 'dry bulb' shows the temperature of the air. In a day when the air is dry, the evaporation from the muslin goes on rapidly, and the wet bulb shows a temperature lower than the dry bulb. The difference becomes less as the humidity is greater, until, when the air is saturated, the two readings are the same. From the two readings of the dry and the wet bulb thermometers we can calculate, by means of tables constructed for the purpose, a number of important particulars regarding the vapour of the atmosphere at the time; among others, the dew-point (par. 237), and the relative humidity. Complete satura-

tion is reckoned 100, and perfect dryness 0. In Great Britain, a day when the humidity is 73 feels very dry. During the virulent east winds of spring, however, the humidity is sometimes much lower, having been observed as low as 30. On the ocean the humidity is always great; in sandy deserts it has been recorded as low as 11.

229. **Condensation** is the reverse process of evaporation; it is the return of vapour to the state of water. If the jar with its saturated air at 80° were suddenly cooled to 70° or 60°, the interior would be filled with a cloud of fog, and the glass become misty. At the lower temperature the air can no longer contain all its vapour, and part of it is thrown out and collapses, or is *condensed* again into water, but in specks so minute that they float in the air or adhere to the glass like a mere dimness.

230. **Clouds.**—What we have supposed to take place in the jar is what is constantly occurring on the large scale in nature in the formation of clouds, fogs, and dew. When a stratum of moist air is from any cause reduced some degrees in temperature, a part of its moisture is thrown out in the form of a fog or cloud; for a cloud is merely fog in the upper regions of the atmosphere. A frequent cause of cloud formation is the mixing of a current of warm moist air with a colder current; but the chief cause is the cooling produced by the ascent and expansion of air that has imbibed heat and moisture from the earth's surface.

231. **Effects of Dust in the Air.**—Recent researches make it appear that the formation of fog in the air is greatly dependent on the presence of dust; some kind of solid nucleus would seem necessary to the condensation of the vapour into cloud-globules. The extraordinary

fogs that often envelop London and the Clyde at Glasgow, would seem to be owing partly, at least, to the solid particles constituting smoke.

232. **What keeps the Clouds suspended.**—If clouds consist of liquid particles of water, what keeps them suspended in the air? Why do they not always descend in a shower? The truth is, that they are always descending, though slowly; but in most cases they have not descended far until they meet with warmer, or, at all events, drier air, in which they are again dissolved. This accounts for the rapidly changing shape of clouds; they are receiving additions at one part, and are melting away at another.

233. **Rain.**—But when the whole air between a cloud and the earth is saturated, the cloud extends lower and lower, and the foggy particles unite in their descent to form drops, which fall to the earth as rain (see par. 240).

234. **Dew.**—Dew differs from fog in this, that it does not form in the air, but on the surfaces of solid bodies. In a warm summer day, when you fill a glass tumbler with cold spring water, the outside soon becomes dim, and drops begin to trickle down the sides. This is a type of the phenomenon of dew. Whenever there is dew, there is some solid object colder than the dew-point of the surrounding air (see par. 237); the film of air next the cold body loses heat by contact, and must deposit part of its vapour, which adheres to the body in minute specks.

235. **How Bodies at night become colder than the Air.**—In the case of the bedewed tumbler the cooling was effected artificially; in ordinary cases it takes place by a process of nature's own. The explanation is to be found in the laws of radiant heat (see par. 94). All bodies are

constantly losing heat by radiation. During the day they receive more heat by the rays of the sun than they lose by their own radiation; but during the night there is only loss, and their temperature continues to fall. The air itself loses heat by radiation, but much more slowly than other things; and thus it arises that the surface of the earth at night is, as a rule, colder than the air resting upon it.

236. **Concurrent circumstances necessary to Dew.**—Why then, you may ask, is there not dew every night? Now, several conditions are necessary to dew. (1) In the first place, it is necessary that the air contain a certain amount of moisture. Very dry air may be cooled down greatly, and still be capable of holding all the vapour it has, and then there is no possibility of dew, as happens during the summer months in such dry climates as that of Syria. (2) Another circumstance that promotes the deposition of dew is a *clear sky*. When there are clouds, they act like a curtain, and throw back some of the rays of heat that are streaming off from bodies, so that the cooling goes on more slowly. Hence there is oftenest dew on clear nights. (3) A third condition of dew is *stillness*. In a windy night the air is constantly brushing over the surface of bodies, and the same film does not remain long enough in contact to become cooled to the dew-point.

237. **The Dew-point.**—Whenever the air is not saturated, there is a point below its present temperature, to which if it were reduced, it would be saturated, and would begin to deposit dew; that temperature is the dew-point. Suppose the temperature of the day (or night) to be 60°; let a portion of the air be shut into a glass vessel along with a thermometer, and let the whole be cooled artificially till the glass begin to grow dim; the temperature

marked at that instant by the inclosed thermometer—say in this case 50°—is the dew-point of the air at that time and place. Some hygrometers are constructed on the principle of showing the dew-point. When the air is saturated, the temperature of the air and the dew-point are the same; and the greater the dryness of the air, the greater of course is the difference between the two temperatures.

238. **Hoar-frost.**—When the temperature is below 32°, the moisture is deposited in the form of particles of ice—hoar-frost.

239. **Latent Heat of Condensation.**—We have seen that evaporation produces cold by the absorption of heat in a latent state (see par. 227). When vapour is again condensed to water, all that heat is given out again. The formation of an ounce of dew has restored as much heat to the atmosphere as would raise 10 ounces of water from 32° to 46°. On many nights frost is thus prevented by a moist atmosphere. The vapour not only acts like a blanket, and retards radiation, but by its latent heat it prevents the temperature sinking much below the dew-point.

RAINFALL.

240. **The Greatest Falls, how caused.**—We have seen the general conditions of a fall of rain (see par. 233). The greatest falls of rain take place where warm winds from the sea meet a ridge of mountains in their course. In sweeping over the sea, the air has taken up as much moisture as it can contain, or nearly so; and when it comes to high ground it has to rise up hundreds, or even thousands, of feet, before it can get over. The cold produced by this elevation and consequent expansion condenses the vapour, and rain comes down often in torrents. When the air descends again to the level

ground on the other side of the heights, it is comparatively dry; and therefore little or no rain occurs in the country on the lee side of the mountains, the amount rapidly diminishing as lower levels are reached. Thus the warm, moist winds from the south-west, that prevail so much in Great Britain, deposit the greater part of their moisture on the hilly regions in the west of the island; so that the east coast receives considerably less rain in the course of the year than the west. Another example is seen in South America: there the trade-winds, laden with moisture from the Atlantic, sweep over the eastern plains, depositing little of their burden by the way, till they come against the barrier of the Andes, where the rains come down copiously, and feed the mighty rivers of that continent. The western slopes in Peru are utterly rainless.

241. **The Rain-gauge.**—The amount of the rainfall at a place is measured by means of an instrument called a rain-gauge, of which there are various forms. One of the simplest is a metal funnel having a receiving area of 17·33 square inches, set in the top of a cylinder, so as to prevent the water collected from evaporating. As a fluid ounce contains 1·733 cubic inches of water, every fluid ounce collected in the cylinder indicates a fall of $\frac{1}{10}$th of an inch.

242. **Average Rainfall in different Regions.**—Nothing is at first sight more capricious than the varying amounts of rain in different regions. Yet the meteorologist, knowing the prevailing winds at any particular place, the configuration of the land, and its position regarding the ocean, could show beforehand that the rainfall of such a place must be excessive, or scanty, or medium, as the case may be, by simply applying the principles of evaporation and condensation above explained. Evapor-

ation is naturally greatest in tropical regions, but a good deal of the vapour there raised is carried in the upper currents of the air, and precipitated in the temperate and polar zones. Still the rainfall is much the greatest in low latitudes, and decreases towards the poles. The average at the equator has been estimated at 95 inches; at Stockholm, 20 inches; in Finland, 15 inches. The average of the north temperate zone has been estimated at 37 inches; but the local deviations are great. At Edinburgh the fall is 26 inches; at Glencroe, in the west of the island, it is 128 inches. At London it is 25 inches; at Bristol, 32 inches; at Kendal, 50 inches; and at Seathwaite, 139 inches.

The following are some examples of the annual rainfall in the tropics: Singapore, 97 inches; St Benoit (Isle of Bourbon), 163 inches; Sierra Leone, 87 inches; Pernambuco, 109 inches; Rio Janeiro, 59 inches; Maranhao, 280 inches. The heaviest annual rainfall on the globe is 492 inches (41 feet), on the Khasia Hills. The south-west monsoons, sweeping up the Bay of Bengal, and over 200 miles of low swamp, come against the abrupt face of these hills, are thrown upwards, and there deposit their load of vapour.

243. **Extraordinary Rainfalls.**—In Great Britain generally, if an inch fall in a day, it is considered a very rainy day. In many parts of Scotland three inches not unfrequently fall in one day. But it is in tropical countries that the heaviest single showers have been recorded. On the hills above Bombay, a fall of 24 inches in one night is recorded; and on the Khasia Hills, 30 inches on each of five successive days.

244. **The number of days** on which rain falls is equally important with the annual amount. In tropical countries there are generally one or two rainy seasons,

the rest of the year being dry; in temperate regions, the rain is more equally spread over the year. The equatorial fall of 95 inches is confined to 70 or 80 days; in London, rain falls on 178 days, although the whole amount is only 25 inches.

245. **Rainless Regions.**—The western slopes in Peru are utterly rainless; the barrier of the Andes having drained the eastern trade-winds from the Atlantic of all their moisture. One great tract on the globe is known as the 'rainless district.' It begins with the Sahara of Africa, and extends north-eastward, embracing Egypt and the greater part of Arabia, Persia, and Afghanistan. It is interrupted by the great mountain knot called the Pamir Steppe, where the Oxus and Jaxartes rise; but it is resumed in Eastern Tartary, and stretches in the Desert of Gobi to the 120th degree of E. long.

246. **Snow.**—When the temperature of the stratum of air from which the rain falls is under 32°, the vapour or clouds must necessarily be frozen, and the descending particles will be *snow* instead of rain. Snow-flakes are the aggregation or union of frozen particles, just as rain-drops are the union of watery particles. They aggregate,

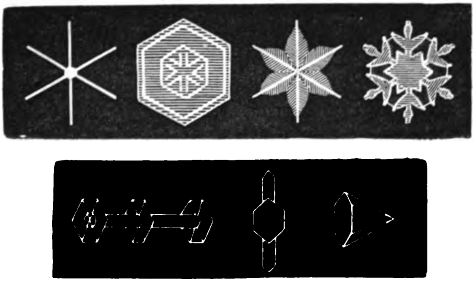


Fig. 33.—Some forms of Snow-flakes.

according to the law of the crystallisation of water, into regular and symmetrical forms, of which the invariable character is a six-sided figure; as for example, six needles branching from a centre, or six arms from a six-sided nucleus, each needle being three or six sided. Though single crystals always unite at angles of 30°, 60°, or 120°, they nevertheless form, by their different modes of union, about 1000 distinct varieties of snow-flake, some of which are figured in the preceding engraving. Any agitation of the air, or an increase of moisture or temperature, destroys, of course, their delicate and beautiful structure.

247. **Hail.**—Hard pieces of ice falling in showers are called hail. How they are formed is not yet quite understood. Sudden condensation of vapour by a downrush of very cold air into a mass of saturated air, is probably the cause of the frozen vapour taking this shape, there being no time, as it were, for the particles to gather together in the particular crystalline forms that they have in snow-flakes.

248. **Ice, its slow formation and slow melting.**—Ice is water in the solid form. The circumstances attending the transformation are stated in pars. 79, 96, and enable us to explain why the freezing of a body of water is such a slow process, and why the ice forms on the top. Ice does not begin to form on a pool or pond as soon as the temperature of the air descends to 32°. The top film of the water, being the first to feel the increased cold, becomes heavier than the rest, and sinks down to make way for a fresh portion, which undergoes the same process; and this goes on till the whole mass is cooled down to 39·2°—the temperature of greatest density of water. As the loss of heat goes on, the upper layer, instead of contracting, now expands, and floats on the

top till it parts with 7° more. Spikelets of ice now begin to form in it, and gradually cohere into a crust. This crust continues to part with heat to the colder atmosphere, and repairs its loss by drawing on the water under it, until it too is reduced to ice, thickening the crust above it; and this goes on so long as the temperature of the air is below 32°.

If you consider the high specific heat of water compared with air, you will see that it must take a considerable time before the whole of a mass of water of any depth, say at the temperature of 50°, is reduced to 39°; and until that is done, freezing cannot even begin. In fact, it is only on shallow pools that one night's frost is sufficient to form ice; and very deep lakes never freeze at all except in rigorous climates. But even when the freezing begins, the process is slow; for every film of water at 39° must first give up 7° of sensible heat, and then its 140° of latent heat, before it can become solid.

The same causes make the process of melting equally slow. Ice—and the same thing is true of snow, which is just ice in a granular condition—does not turn instantly to water whenever a thaw comes. Every film that melts must absorb 140° of latent heat, which it draws slowly from the air. And happily so; for were snow and ice to melt all at once, the whole surface soil would soon be swept into the sea.

Not less beneficent is the provision by which ice forms at the top. If water, instead of expanding from 39° to 32°, went on contracting, the particles of ice as they formed would sink to the bottom, and the deepest lakes would soon become masses of solid ice, which the hottest summer could not melt.

AIR CURRENTS.

249. **Primary movement of the Atmosphere as a whole.**—The prime cause of all movements in the atmosphere is the unequal distribution of heat, from which arises unequal pressure (par. 77). On a calm day, pile up a heap of straw or wood shavings, and set it on fire. As soon as the flames begin to ascend, those standing round feel a draught setting towards the fire from all sides, and the currents may be made visible by a flaming piece of paper held at a considerable distance. The heated air and other gases are ascending above the fire, and the colder and heavier air around is pressing in to supply the vacancy. This is a type on a small scale of what goes on on a great scale on the globe. The air over the torrid zone is constantly ascending, and a movement from the temperate and polar regions on both sides sets in towards the equator; while the ascending air in the middle overtops the rest of the atmosphere, and flows north and south towards the poles. The movement illustrated in fig. 20 is similar to that of the circulation of the atmosphere thus simply conceived, and apart from the many modifications it undergoes. One modification is general, affecting the whole system; the others are partial, owing to local peculiarities in the distribution of heat and pressure.

250. **Trade-winds.**—The general modification spoken of arises from the rotation of the earth on its axis. The circumference being 25,000 miles, a spot at the equator travels this in twenty-four hours, or upwards of 1000 miles an hour. But a glance at a globe makes it apparent that places north and south of the equator move more and more slowly; in lat. 60° the circle they have to travel is only half as long. Now, the atmosphere

is part of the globe, and rotates with it, so long as each portion keeps in the same latitude. But when the air over say 60° N. lat. begins to move southwards, it is constantly coming to places which are moving faster, and before it has time to acquire the new velocity (which it would eventually do through friction) it lags behind, so that its motion, instead of being directly south, slants westwards—in other words, it becomes a north-east wind.* Similarly, the current from the south pole becomes a south-east wind. On the other hand, the upper return currents from the equator to the poles carry with them an eastward velocity greater than the places over which they are passing; they therefore shoot ahead of the earth's surface—like a rider whose horse suddenly slackens its speed—and move, the north current toward the north-east (a south-west wind), the south current towards the south-east (a north-west wind). When the currents from the north-east and south-east meet, they necessarily take the direction of direct west; and thus there is a zone extending on both sides of the equator where the winds blow constantly westwards. It is only on the Atlantic and Pacific Oceans that this current can maintain itself uniformly; and there it is known as *trade-winds.* Where land intervenes, it is modified and often overborne by local causes. The upper currents towards the poles descend in great measure to the surface in the temperate zone, and form the *return trades.* To these belong the south-west and west winds that prevail in the North Atlantic and on the coasts of Western Europe; and similar westerly winds prevail in many parts of the Southern Hemisphere.

---

* Air-currents are named after the points *from* which they come; ocean-currents, after the points *towards* which they flow. This inconsistency of language sometimes gives rise to confusion.

251. **The Region of Calms.**—Where the two polar currents meet and interfere with one another, as it were, there is a narrow belt subject to intense calms and to heavy rains and thunder-storms. This region of calms, known as the *Doldrums*, does not coincide with the equator, but lies some degrees north of it. The cause of this is to be found in the greater amount of land in the northern hemisphere, causing more heat to be developed from the sun's rays, so that the thermal equator is made to lie north of the geometrical equator. The region of calms is not stationary, but follows the sun, moving northwards in summer, and southwards in winter.

252. **Sea-and-Land Breezes.**—When the sun shines with equal force on coast-land and on the adjoining sea, the land becomes hotter than the water (see par. 84). The air above it ascends, and the heavier air from the sea rushes in. In the absence of the sun, the earth soon becomes the colder of the two, and the contrary movement goes on. Thus during the day there is a breeze from the sea to the land, and during night from the land to the sea. These breezes are felt on all sea-coasts during sunny weather, when not overborne by stronger winds.

253. **Periodical Winds—Monsoons.**—Periodical winds are defined to be those that blow during a period of the year in one direction, and for a corresponding period in the opposite direction. Sea-and-land breezes are therefore periodical winds; but the term is usually applied to winds that alternate with the seasons of the year, and not with day and night; they both, however, occur in exactly the same way. The most important of the periodical winds are the *Monsoons*, experienced in the Indian Ocean, and on the coasts of India and China. During the winter half of the year, the wind in those

parts blows chiefly from the north-east. There are local deviations, but the main direction is towards the equator. This is called the *north-east monsoon*; it is really, however, nothing more than the ordinary north-east trade-wind caused by the superior heat of the equatorial parts of the globe, and augmented largely by the great cold and high pressure of the interior of the continent. But in summer, when the sun is north of the equator, and nearly perpendicular at noon over a great part of Southern Asia, the land there is kept much hotter day and night than the ocean; and a strong sea-wind sets in from the south-west. This lasts from April to October, and is popularly called the *south-west monsoon*, though its direction is in some regions from the south or the south-east. At the changes from the one to the other in April and October, when the two air-currents are contending for the mastery, there are furious storms of wind, rain, and thunder.

254. **Variable Winds** are caused by a variety of local circumstances. Some of them have special names. The *mistral* is a violent north-west wind blowing down on the Gulf of Lion, and felt particularly in the south-east of France. The *sirocco* is a hot, parching wind from the desert, blowing over Palestine, Sicily, the south of Italy, and Spain.

255. **Storms—Cyclones.**—The origin of winds in general is stated in par. 249; and a storm differs from an ordinary wind only in its being sudden and violent. The movement in a storm is always cyclonic. There is a sudden and excessive diminution of pressure over a considerable area, and towards this partial vacuum currents set in on all sides; not, however, directly to the centre, as we might expect, but obliquely. The obliqueness is owing to the same cause that affects the air currents to

and from the poles. Let the centre of depression be over the English Channel. The current starting from the south of France, instead of proceeding directly north, is, for the reason given in par. 250, deflected to the north-east, while the current from Scotland turns a little westward. The indraught from east and west is direct to the centre; but the effect of the north and south currents is to give the whole a spiral direction, and to set a large tract of the air round the central depression into a whirl, the direction of which is contrary to the sun's course or the movement of a watch hand. If this is the true account of the whirling motion of storms, it ought always to be in this direction in the northern hemisphere, and in the opposite direction in the southern hemisphere. This is found to be the fact, and thus the theory of the origin of cyclones is believed to be established.

256. **Gradients.**—When the height of the barometer decreases rapidly as we proceed from the circumference of the cyclone towards the centre, there is said to be a steep *gradient*, and the violence of the storm is in proportion to its steepness. That the inrush of air towards a depression does not immediately fill it up, is accounted for by the continuance of the ascending column from the centre, which is the real cause of the disturbance.

257. **The Centre of the Storm.**—In the centre of the storm there is generally a calm; in other parts the winds are encountered blowing from every possible quarter; but it is always possible to tell in what direction the centre of the storm lies. The rule is this: Wherever you are, stand with your back to the wind, and then the centre is towards the left hand. This of course applies only to the northern hemisphere; in the southern hemisphere it is to the right. A knowledge of

this is important to mariners, as it shows how to steer so as to get out of the cyclone.

258. **The Storm has a Motion as a whole.**—In addition to the circular movement of the air within the cyclone, the whole storm is moving bodily in some definite direction, usually in that of the prevailing wind of the region. The storms that pass over Britain mostly come from the south-west, and proceed towards the continent, at the rate of about 16 miles an hour. The most violent storms occur within the tropics. In the Chinese seas they are known as *Typhoons.*

CLIMATE.

259. **Conditions that determine Climate.**—The climate of a country is its condition as to *weather*. The chief elements in weather are temperature, rainfall, and winds. The general conditions of all these have been already expounded (pars. 217, 219, 240), and a reference to these will explain the climatic peculiarities of any place whose geographical position and surroundings are known. Thus, an island is less liable to extremes of heat in summer and of cold in winter than a part of a continent in the same latitude. An island partakes of the temperature of the surrounding ocean, which is more slowly heated than land in the presence of the sun, and more slowly cooled in his absence. Hence the distinction of *insular* (equable) and *continental* (extreme) climates. It is important to note not only the mean temperature of a place, but the difference between the temperature of the hottest month and of the coldest. The *range* of the temperature has great effects both on vegetable and animal life.

As to aqueous vapour, again, if the prevailing wind comes over a warm ocean, the climate must be moist;

if starting from a cold region, it comes overland, the climate will be dry. Forests and rank vegetation tend to keep the air damp, as the rainfall is thereby prevented from running so rapidly off the surface.

ACTION OF RAIN, RIVERS, ETC.

260. **Denudation.**—The waters that fall from the clouds, in returning to the sea from which they came, do not return alone; in the form of rain, springs, streams, glaciers, they are constantly wearing away the land and carrying it into the sea. When the existing continents and islands rose out of the water, the upheaving forces (see par. 168) would naturally cause certain axes of elevation, broad slopes and undulations, which would determine the direction the streams first took; but, if we may judge from the bottom of the present seas, the deep valleys and ravines, the rugged ridges, and other features of the land as we know it, have been produced by the *denuding* force of water in its various forms.

261. **Weathering.**—Water and the oxygen of the air together are continually disintegrating the earth's crust. Limestone is corroded by water containing carbonic acid. Water attacks the compounds of potash in some minerals, and the other ingredients of the stone crumble to powder. It is in this way that clay results from the disintegration of felspathic rocks (see par. 120). The potash is washed out, leaving the silicate of alumina. When the felspar is free of iron and other impurities, we have the finest kind of porcelain clay, known as *kaolin*. Some compounds attract an additional equivalent of oxygen, and become disintegrated. But frost is the great disintegrater. Water entering the surface pores of a stone, expands when frozen, ruptures the pores, and with the thaw a film of the stone peels off. Cracks in rocks

are gradually widened by the freezing of water in them, and large masses are thus from time to time dislodged from cliffs and hurled to the bottom. Even without water the alternate expansion and contraction of rocks by heat and cold, has a tendency to make them splinter. The debris of these weathering processes is being constantly carried to lower levels by rain and wind. It is of this material that the mineral part of surface soil is composed; but the greater part has been carried by rivers into lakes, which are thus gradually filled up, and into the sea to form deltas and submarine deposits.

262. **Erosion by Rivers.**—Watch the effect when a sudden heavy fall of rain causes streamlets of water on the highway or on a garden walk; the ruts formed in an hour or two will enable you to conceive how the thousands of mighty rivers and the countless torrents and rills must have furrowed and wasted away the solid land in the course of the unfathomable past.

A ravine is manifestly a rut worn by the stream running through it. A ravine is gradually widened by the stream undermining first one side and then the other of its channel; and the sides are rendered less precipitous by landslips and the wear of secondary rills. The rounded slopes of the wider valleys are owing to the action of ice (see par. 266).

263. **Effects of a Flood—Alluvial Plains.**—It is a mountain stream in flood that gives the best notion of the erosive power of running water. It then hurls along fragments of rock, which rub one another till they become round pebbles, and grate away the bottom and sides of the channel; the rivulets that feed it are carrying in on all sides the finer matter resulting from weathering; and thus the river becomes a mixture of water, stones, sand, and mud, overflowing its ordinary

channel, and filling the bottom of the valley. As it slackens its pace, it deposits its burden, first the coarsest material, and then the finer; the finest of all being carried into the sea to form *deltas.* The matter deposited by the overflow of rivers forms alluvial meadows. Rivers that flow into lakes there deposit the matter held in suspension, and flow out pure and transparent. Lakes are thus gradually silted up, and in the end become alluvial plains.

264. **Action of Water on Limestone.**—This action is of a chemical nature. Limestone (carbonate of lime) is hardly, if at all, soluble in pure water; but when the water contains carbonic acid, it dissolves the limestone (or chalk) freely. Now, rain brings down with it carbonic acid from the atmosphere, and in sinking through the superficial soil, it imbibes still more from decaying organic matter. In afterwards trickling through the cracks of limestone rocks, it eats them away and forms cavities. Hence the caverns, sometimes miles long, with which many limestone regions are honeycombed.

265. **Hard Water.**—Water issuing from chalk or other limestone strata is thus always charged with dissolved carbonate of lime, and is known as hard water. One grain of the carbonate in a gallon is counted 1° of hardness. Up to 6° water may be reckoned soft; 8° is moderately hard; at 16° the hardness is excessive. Springs from chalk strata commonly range from 16° to 18° of hardness, but some springs are four or five times as hard.

The quantity of limestone thus carried into the sea in solution is truly vast. It has been calculated that the Rhine carries into the German Ocean annually as much carbonate of lime as would form a bed of limestone a foot thick and four square miles in area. Notwithstanding this, the relative amount present in sea-water is surprisingly small (see par. 170).

MELTING-SNOW, GLACIERS, ICEBERGS.

266. **The Snow-line.**—A temporary covering of snow, when melted, has much the same denuding effect as rain. Every one is familiar with the idea of lofty mountain summits remaining white throughout the year, even in warm countries. There is everywhere a limit of elevation above which the heat of summer is insufficient to melt all the snow that falls. This limit is the *snow-line.* Its average height in the tropics is eighteen miles, and it generally declines towards the polar regions. The height of the snow-line is not regulated by latitude alone, but is modified by local peculiarities. On the north side of the Himalayas, for example, it is 19,000 feet; on the south side, 15,000 feet. The explanation of this anomaly is to be found in the principle stated in par. 229, and in the greater condensation of vapour on the south side, and greater dryness of the air, and consequent evaporation, on the north side.

But although summer does not melt all the snow on high mountains, it melts a great part of it. The powerful rays of the summer sun send torrents of water from snowy mountains into the valleys below; and hence rivers that have their head sources in such mountains are full and turbid in summer, and comparatively shrunken up in winter. This is the case with the Rhine, the Rhone, the Indus, and others.

267. **Glaciers.**—It is natural to ask why, in the course of years, the snow on lofty mountains does not accumulate to an indefinite depth. Now, snow summits rid themselves of their growing burden in two ways. In some places it is hurled down in *avalanches* to a lower

level, where it melts; in other places it moves down as rivers of ice—*glaciers.* The glaciers of Switzerland are the best known, and their origin may be thus described: The upper end of an alpine valley has generally a cup-shaped expansion. In this the snow accumulates by sliding down from the slopes. Such an accumulation is called a *névée.* The depth is often hundreds of feet, and the pressure of the mass on the lower strata condenses the snow into ice, and pushes it down the slope. That pressure turns snow into ice you can verify for yourselves, if you will squeeze and knead a snowball long enough. The ice thus formed at the bottom of the *névée* behaves as if it were a viscous fluid like honey. It flows down the valley by gravity, obeying the windings, contractions, and expansions like a river. When it comes to a precipice, it tumbles over in fragments—a cataract of ice; but the pieces unite at the bottom, and continue their course as before.

268. **How Ice becomes plastic.**—How is it that a substance, any piece of which is brittle like glass, can behave in the mass as if it were plastic? This anomaly is explained by the fact that ice, under pressure, melts at a temperature below 32°. Put a piece of ice at 32° under a piston, and subject it to a pressure of several atmospheres. A portion of it melts; but in becoming water it requires latent heat, and this it takes from the remaining ice and from its own substance, cooling both below 32°—say to 30°. No sooner, however, does the water thus cooled down escape from under the pressure, than it turns to ice again. Now, within the substance of a piece of ice under pressure, the stress must bear more on some points than on others. At such a point a small quantity of the ice melts, and the water escapes into the minute cracks which the crushing force produces around

the spot; but the pressure being now removed, it immediately congeals and solders up the cracks again. The ice is thus able to yield and change its shape without losing its continuity.

269. **Glaciers move without slope—Icebergs.**—It does not require a valley, or even a slope, to make a glacier. If constant additions were made to a snow-field even on a plain, the pressure and partial melting would convert the bottom layers into ice, and make it spread out in all directions. The whole of Greenland is enveloped in one continuous glacier or ice-cap, which is in constant motion towards the coasts. Opposite the mouths of valleys the glacier, thousands of feet thick, protrudes for miles into the sea, until the buoyancy of the water breaks off a mass which floats away as an iceberg.

The South Polar land, within the parallel of 70° S., is enveloped in a similar covering, presenting everywhere ice-cliffs of the nearly uniform height of about 200 feet. The ice-sheet must extend considerably beyond the land, and dip into the water to a depth of about 200 fathoms. Masses are being constantly torn off from this margin, and form the tabular icebergs of the southern seas. Being usually about 200 feet above water, they must have a depth in all of at least 1400 feet.

270. **The Depth of the Ice-cap limited.**—The ice sheet would seem to be limited to this thickness by its own weight. This weight not only makes it spread out by a glacier movement, and waste itself at the margin, but it causes melting below. The soil on which the ice rests, being protected from external cold, may be assumed to be about the same temperature as the surrounding sea-water, or from 32° to 28°. The weight of the mass will thus be able to cause liquefaction in the lower strata, the water working out channels for itself between the ice

and the land. It is well known that great streams of muddy water issue into the frozen sea from below the great glaciers of Greenland, winter as well as summer.

271. **Moraines.**—A valley glacier, like those of the Alps, carries on its surface, stones and other debris that fall from the sides of the valley. When the glacier has extended so low that it melts as fast as it advances, the rubbish is deposited, forming a *moraine.* Long lines of it are also formed at the margins, when the glacier contracts in breadth in summer. Great quantities of sand and stones are imbedded in the substance of the ice; and thus a glacier, as it creeps along, acts like a huge rasp or polishing machine, wearing away the rocks, and leaving them rounded and covered with *striæ* or scratches. The water arising from the melting of the surface in summer may be seen running in considerable streams, wearing out channels on the surface of the ice. When such a stream comes to one of those *crevasses* or cracks which are found here and there in glaciers, it plunges to the bottom, where it forms channels, and flows out at the foot, a turbid river, charged with the mud formed by the grinding action of the glacier.

272. **Ancient Glaciers.**—Noting the effect of existing glaciers on the ground over which they slide, and observing like features elsewhere, we infer with certainty that there were glaciers at one time where none have been seen in the memory of man. Geologists have collected unquestionable proofs that much of the lands in the north temperate zone were for ages covered with ice, as Greenland is now. The strata known as the till or boulder-clay is believed to be the work of such wide-spread glacier action. The Greenland glaciers that protrude into the sea are at the present day forming similar deposits—submarine moraines.

273. **Ice-foot, Floes, Pack.**—A belt of ice often thirty or forty feet thick forms along the sea-coast in Arctic regions, and is known as *ice-foot.* Blocks of stone and other debris fall from the cliffs; and as large portions become detached in summer, they float away with their load, which is deposited when the ice melts or is broken up. Many *erratic blocks,* as they are called, are believed to have had this origin. Outside the ice-cliffs of the South Polar land a similar fringe of ice is formed in winter, and broken up in summer. A floating field of unbroken ice is called a *floe.* When a floe is broken up by storms, and the fragments drifted close together, it forms the ice-pack or *pack*, of which we read in Polar expeditions. 'The Polar basin,' says Sir Wyville Thomson, 'or at all events such portions of it as have been hitherto reached, is neither open sea nor continuous ice, but a fatal compromise between the two, an enormous heavy pack formed by the piling up and crushing together of the floe of successive years, in frequent movement, breaking up and shifting according to the prevailing direction of the wind, and leaving open, now here and now there, lanes and vistas of deceptive open water, which may be at any moment closed and converted into a chaotic mass of hurtling floe-bergs by a hurricane from another direction.'

ATMOSPHERIC AND TERRESTRIAL ELECTRICITY.

274. **Ordinary Electricity of the Atmosphere.**—It is commonly said, when one sees a sultry cloudy sky, that the air is electrified; yet in all kinds of weather, clear as well as cloudy, it is more or less electrical. The cause of this is not very well known, but it is usually ascribed

to friction and evaporation. One theory is, that mere contact of the particles of aqueous vapour with those of air, as they fly about, and impinge according to the modern kinetic theory of gases, produces a separation of the two electricities; just as, when zinc and copper are brought into contact, the zinc becomes positively electrified, and the copper negatively. Thus the electrification is supposed to be the result of chemical affinity. When vapour is precipitated in the form of cloud, it takes billions of vapour-particles, we are told, to form a cloud-particle or molecule of water. However small, then, the electric charge on a single vapour-particle, if it exists in any degree, the accumulation of electricity on the mass of water-particles forming a cloud would be enormous.

A clear sky is always *positively* electrical; in cloudy weather, it is sometimes positively, sometimes negatively electrical: and rain, snow, hail, &c., when caught on an electroscope, are found sometimes positive, sometimes negative; nay, not unfrequently changing suddenly during the same shower.

275. **Thunder-storms.**—In summer the usual result of a few days' strong heat and copious evaporation is to produce vast masses of cloud highly charged with electricity, sometimes positive, sometimes negative, no cause being yet assignable for the difference. When two oppositely charged clouds are borne by the wind within attracting distance of each other, they rush together, and their electricities combine with terrific vividness; and this is the extraordinary development of atmospheric electricity that we call a thunder-storm. An electrified cloud always induces the opposite electricity on the part of the earth under it, and when the cloud descends sufficiently low, the discharge takes place between the cloud and the earth, and the storm is then most dangerous and awful.

276. **Lightning.**—Franklin was the first to identify the lightning flash with the electric spark, by his famous kite experiment. The same disruptive, burning, and luminous effects are common to both, though in vastly different degrees. An electric spark three feet long is considered something great even for a powerful machine; but the lightning-flash often exceeds a mile in length, and sometimes extends to four and five miles.

There are several kinds of flashes. First, there is the *forked-lightning*, or zigzag line of bright light which may be seen darting between clouds, or from the clouds to the earth. Often it splits up, as it approaches the earth, into branches several thousand feet apart. Its zigzag form is owing to the unequal resistance of the air, the path taken being that of least resistance through the different strata of air.

Second, there is the large indefinite blaze of *sheet-lightning*, which we see more than twenty times for once that we see forked lightning. It is ascribed to an electric discharge within the clouds themselves, which illuminates their mass for a moment. When it occurs at a great height or distance, no thunder is heard, and a vague flash passes across our field of view; and it is highly probable that weak discharges occur without any audible sound. Such lightning is common in summer evenings.

A third and less frequent form is that of *ball-lightning*, which rather resembles a meteoric than an electric phenomenon. It is said to occur in this way. After a violent explosion of lightning, a ball is seen bounding like a bomb to the earth. When it reaches the ground, it either splits up at once and disappears, or it rebounds like an elastic ball before doing so. It may last as long as ten seconds, and is thus very different from the flash, which has been proved to last less than one ten-thousandth of a second. It is very dangerous, and readily sets fire to any building in its way. This form of electric discharge is, if possible, more difficult to explain than the other form, nothing of the kind being produced by the electric machine.

277. **Thunder.**—The snap of the electric spark is heard on a grand scale in the thunder-clap, which accompanies the lightning. The origin of the sound is to be found in the instantaneous dilatation of the air along the track of the lightning flash, caused by the excessive rise of temperature that renders the air for the moment so brilliantly incandescent. There is thus a sudden compression of the air all round the track of the spark, and then a rapid rush of the air into the partial vacuum thus produced.

The sound must originate at the same instant along the whole track of the flash. Whence, then, the prolonged rolling and strange rising and falling of the peal? Two chief causes may be assigned. In nine cases out of ten, we must be nearer one end of the lightning track than the other. Suppose the one end a mile farther off than the other; owing to the time sound takes to travel, the sound from the farthest point will come to the ear five seconds after that from the nearest, and the arrivals from the intermediate points will form a continuous roar. Further, sound is reflected not only from clouds, but also from undulating surfaces of the earth, and even from the bounding surfaces of masses of air of different density. The primary sound is thus repeated again and again with every variety of loudness. The distance of the flash, as a whole, from the observer is roughly estimated by allowing five seconds to a mile for the sound to travel. Thunder is not heard at such a distance as we might expect from its loudness; nine or ten miles seem to be the ordinary limit, and twelve miles the maximum limit. But the discharge of a single cannon has been often heard fifty miles off; and the cannonading at Waterloo is stated to have been heard at Creil, in the north of France, about 115 miles from the field.

278. **Lightning-conductors.**—Electricity, like any other force, always takes the easiest route. If we hold a pointed rod of metal to the prime conductor of a machine, its electricity will be all drawn silently off to the ground, as fast as it is produced. In the same way, if we present a pointed rod near to a charged cloud, its electricity will pass silently and harmlessly to the earth. This is the principle of the lightning-conductor. It is a pointed rod of copper or galvanised iron, reaching from eight to thirty feet above a building, and carried down to the earth, in which it is carefully buried. The part above the building is called the *rod*, and the rest the *conductor*, which is now generally in the form of a metallic ribbon. The whole must be very carefully constructed, otherwise its presence is the opposite of protective. It is led down two feet or so into the ground, and then turned away into a well or other water, if possible, or else into a drain filled with charcoal for twelve or sixteen feet. In large buildings, there are several rods all connected to one common conductor. In ships, there is one on each mast, leading to the metal of the keel. When properly made, they are, beyond all doubt, sufficient protection from the ravages of lightning. A striking illustration of this effect is furnished by what we are told of Pietermaritzburg, in Natal: 'Till lightning-rods became common in that town, it was constantly visited by thunder-storms at certain seasons. They still come as

frequently as ever, but they cease giving lightning flashes, whenever they reach the town, and they begin again to do so as soon as they have passed over it.'

Sometimes a luminous brush is seen round the point of a lightning-rod. This is the St Elmo's fire of the sailors, frequently seen at the points of masts and spars. The fall of rain and hail aids in discharging a thunder-cloud; so much so, that rain-drops often give a spark just before touching the ground. When this occurs at night, we have the phenomenon of 'luminous rain.'

279. **Earth Currents.**—The earth is a great magnet, and its surface is pervaded by lines of magnetic force; and we know (see par. 74) that it is sufficient for a conductor to cross such lines to have an electric current produced in it. Again, any two conductors differing in construction, with a fluid between them for which they have any affinity, become oppositely electrified, and are ready to maintain a current (see par. 65). Thermo-electric combinations also (see par. 75), of a more or less effective kind, must occur in almost every body, or system of bodies, in nature. We are thus surrounded on all hands by electric currents. They are for the most part feeble, and unprovided with wires or other regular channels to flow in, so that their presence is not easily detected; but they must be there. The telephone and microphone are making us alive to their existence in cases where it had not been suspected.

But, besides these local and circumscribed manifestations, more powerful currents are often observed flowing through the earth for hundreds of miles in the same direction. The cause of these has not yet been ascertained with certainty. Sudden disturbances in these currents cause what are called *magnetic storms*, producing rapid variations in the earth's magnetism, and deranging the working of electric telegraphs. These storms are found to be intimately connected with the sun-spots, and to vary in frequency and intensity with them, having the same cycle of about eleven years.

280. **The Aurora or Polar Lights.**—The appearance of auroras is familiar to every one. That they are electrical phenomena is undoubted, but how they are caused is only matter of conjecture. Nothing is known with certainty as to the height of auroras, or even as to what it is that is rendered luminous. The geographical extent must often be vast, the same aurora being occasionally seen over not only a whole hemisphere, but nearly the whole globe. One theory ascribes the phenomenon to inductive electrical effects of changes in the earth's magnetism. This opinion is favoured by the fact that they are usually coincident with magnetic storms.

281. **The Mariner's Compass** consists essentially of a magnetised bar of steel, called the needle, supported horizontally on a central pivot, round which it is free to move and point in any direction. A circular card, like the dial of a clock, is fixed to the needle so as always to move along with it, and round this card are marked thirty-two equidistant points. The four cardinal points, north, south, east, and west, are indicated by their initials respectively; while the subordinate ones are marked by various letters, as NbE for north-by-east, NNE for north-north-east; and so on. To know from the compass where the true north lies, the mariner must know the declination of the magnet (see par. 54) at the particular part of the earth where he is, and this information is furnished by his sailing charts. An iron vessel becomes magnetic through the induction of the earth's magnetism, and various arrangements have to be made to guard against this disturbing influence on the compass.

CHANGES UNDERGONE BY THE EARTH'S SURFACE IN PAST AGES.

282. **Changes in the Conformation of Land and Sea.**—The forces still at work altering the surface of the earth have been described in several of the preceding sections; and numerous facts have been adduced, showing the vast effects thus produced in the course of geological time (see pars. 151, 152, 155–168, 177, 260–273). Wherever we see stratification we have ocular proof that that portion of the present land surface had been for ages under water, and had then been upheaved into its present position. The several strata have been arranged by geologists according to the order of their super-position and the character of the fossils they contain, into regular chronological series—*Formations* as they are called; and from these, as from the leaves of a record, they have learned to spell out to a considerable extent the history of the earth's crust. They can affirm, for example, with confidence that 'some of the most marked features of the globe's surface are of comparatively modern date; for neither the Alps nor the Himalayas had any existence before Eocene times. At the time the nummulitic limestone was accumulating, the sea flowed over the sites of these mountain ranges, and over the areas where in subsequent ages the Pyrenees and the Carpathians made their appearance. In short, it becomes evident that, during the deposition of the Eocene strata, Europe existed as an archipelago—the sea then covering large areas which are now dry land.' —*Historical Geology*, by James Geikie, F.R.S., author of *The Great Ice Age.* (W. & R. Chambers.)

283. **Alternations of Climate.**—Not only have the conformations of land and sea undergone vast changes; there are also evidences of great variations in climate. In the British Isles, and even in the Arctic regions, there are found fossil remains of kinds that now live only in tropical or sub-tropical countries. More than this, these tropical conditions seem to have repeatedly alternated with ages of glacial cold—ages when 'Scandinavia, like Britain, was invested with an ice-sheet which filled up the Baltic, and extended into Northern Germany. The Swiss and other glaciers of Europe greatly exceeded in size their present puny successors. All North America was covered with ice down to the latitude of New York' (J. Geikie). The cause of these alternations of climate is believed to be found in the periodic increase and diminution to which the eccentricity of the earth's orbit is subject, combined with the precession of the equinoxes. How these movements co-operate to produce the effects in question, falls to be explained in the Advanced Course of our subject.

284. **Changes of Flora and Fauna.**—While inorganic nature was undergoing these changes, the face of the organic world was not more fixed. When life first makes its appearance on the geological record, the forms of the organisms were altogether different from any that now exist; and in the lapse of ages the flora and fauna of our globe have been again and again completely changed. Myriads of species of plants and animals have successively appeared and then vanished for ever. But throughout this gradual extinction of old forms of life and substitution of new, there is everywhere manifest a progress from lowly types up to more highly organised structures.

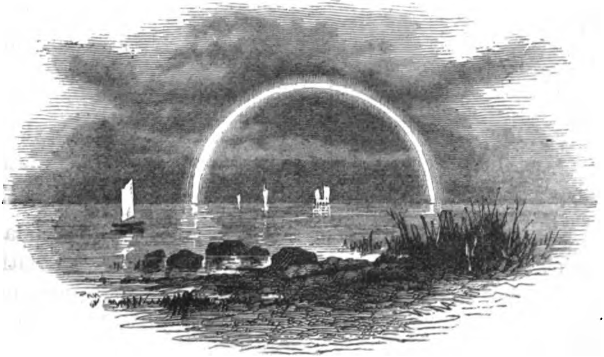
285. **Earth-worms as Agents in changing the Earth's**

Surface.—Among the causes of change in the earth's surface must be classed the agency of worms. In a recent work (*Vegetable Mould and Earth-worms*, 1881), Mr C. Darwin has shown that the mould which covers the greater part of the dry land is the work of these apparently insignificant creatures. In making their burrows they swallow the finer mineral particles of the soil, together with the fragments of decaying organic matter which form their food. These materials are triturated in their powerful gizzards, in which small stones and other hard objects are retained to act as millstones; and the whole being reduced to a fine paste, is voided at the mouth of the burrows as *worm-castings.* Mr Darwin calculates that 'in many parts of England a weight of more than ten tons of dry earth annually passes through their bodies, and is brought to the surface on each acre of land (forming a layer one-fifth of an inch in thickness); so that the whole superficial bed of vegetable mould passes through their bodies in the course of every few years.' It is in this way that objects left on the surface of the earth 'work themselves downwards,' as the phrase is. When a field is laid down in pasture, however stony the surface may be at first, the stones after a few years disappear; worms excavate the earth from below them, and lay it on the surface. It is thus that many ancient ruins have been buried and have lain hid for ages.

286. **How Worms promote Levelling and Denudation.**—Where the surface of the land is clothed with vegetation, the denuding action of the weather (see pars. 260–263) seems in a manner to be shut out. But worms are constantly bringing loose mould to the surface; this, being acted upon by gravity, by rain and wind, is constantly tending to a lower level, while the finer particles

are altogether swept away into streams, and find their way into the sea. It is in this way that worms contribute to a general lowering of the level of the whole dry land of the globe.

Worms may be looked upon as the oldest and still the greatest of agriculturists. 'Long before man existed the land was regularly ploughed, and still continues to be ploughed, by earth-worms.' Mr Darwin compares their castings to the fine soil prepared by a gardener for his choicest plants. 'This earth forms the dark-coloured rich humus which almost everywhere covers the surface of the land with a fairly well defined layer or mantle. . . . It may be doubted whether there are many other animals which have played so important a part in the history of the world as have these lowly organised creatures.' Corals have perhaps done more conspicuous work; but their operations are almost confined to the tropical zones.



APPENDIX.

SYLLABUS OF THE SCIENCE DEPARTMENT, SOUTH KENSINGTON.

SUBJECT XXIII.—PHYSIOGRAPHY.

FIRST STAGE OR ELEMENTARY COURSE.

The candidate will be expected to have a knowledge of ordinary Descriptive and Physical Geography so far as required by the 5th and 6th Standards of 'the new Code' and of the specific special subjects of secular instruction—Principles of Mechanics and Physical Geography. Questions may be set in these subjects.

The parts played by gravitation, cohesion, and chemical affinity in producing chemical and physical differences in matter.

Elementary ideas of the various conditions of matter as regards energy, embracing heated states and electric and magnetic states.

Elementary notions of chemical action, the formation of binary compounds.

Breaking up of compound matter into simpler forms. The chemical elements.

Water, its composition and different states.

Chemical and physical character of the crust of the Earth. Rocks, stratified and unstratified. Inorganic materials: the more frequent simple minerals and rocks formed of them; granite, volcanic products ancient and modern; sedimentary rocks, conglomerate, sandstone, shale; limestone, gneiss, slate, marble, sand, mud, surface soil. Materials partly produced by organisms: Coal, peat, chalk, coral, limestone. Bodies of which these are compounds.

The chemical elements of which the crust is chiefly composed.

Observations indicating an increased temperature in the interior of the earth.

Volcanic phenomena and distribution of volcanoes.

Earthquakes and slow upheavals and subsidences of the Earth's crust.

The Sea:

- Salts dissolved in sea water; depth and form of sea bottom; remarkable inequalities.
- The chief currents.
- Distribution of temperature and density.
- Phenomena of arctic and antarctic regions. Floes, pack ice, icebergs, &c.
- Action of the sea upon the Earth's crust.
- Influence of the sea in the distribution of climate.

The Atmosphere:

- Height and composition; atmospheric pressure; use of the Barometer.
- Distribution of temperature, horizontal and vertical.
- Use of the Thermometer.
- Evaporation and condensation.
- Aqueous vapour, rainfall, ice, and snow.
- Regions of extreme dryness and of great rainfalls.
- The prevailing air currents; cyclones.
- General conditions of climate.
- Action of rain, springs, rivers, and glaciers upon the Earth's crust.

General ideas of the changes which the Earth's surface has undergone in the past.

Elementary notions as to the effects of terrestrial electricity and magnetism. Thunder-storms; aurora; the mariner's compass.

The distribution of light and heat on the Earth's surface. Day and night. The Seasons.

EXAMINATION PAPERS.

1877.

FIRST STAGE, OR ELEMENTARY EXAMINATION.

INSTRUCTIONS.

You are permitted to *attempt* only *eight* questions.

The *first four* questions must be *attempted* by you, and you are then at liberty to select four others from among the remaining questions on the paper.

The value attached to each question is indicated by the numbers in brackets.

---

1. What are deltas? How are deltas formed? Name six of the largest deltas in the world. (15.)

2. Why does rain fall in such great abundance in the west of Ireland? What is meant by the statement that the mean annual rainfall of a place is 70 inches? What becomes of the water which falls upon the earth in the form of rain? (15.)

3. What is meant by the snow-line? Why is the snow-line sometimes higher on one side of a mountain chain than on the other? Why do glaciers descend below the snow-line? (15.)

4. What is a volcano? Name the *active* volcanoes of Europe, and state in what parts of the same continent *extinct* volcanoes occur. (15.)

5. State, in the order of their relative abundance, the eight chemical elements which enter most largely into the composition of rocks. (10.)

6. What is the difference in composition between peat and coal? By what changes would the former pass into the latter? (10.)

7. Of what materials are clay, shale, and slate chiefly composed, and in what respects do these rocks differ from one another? (10.)

8. What is the principal work performed by rivers in modifying the features of the earth's surface? Explain the mode of origin of the winding curves in which rivers so frequently flow. (10.)

9. Draw a sketch map of the Atlantic Ocean, and indicate upon it the courses of the chief of the great currents. (10.)

10. What are the differences between continental and insular climates, and how are these differences caused? (10.)

11. In what direction does a magnetic needle in this country point, and why does it not everywhere assume a due north and south direction? (10.)

12. Why are coral reefs limited to certain restricted areas of the earth's surface? (10.)

1880.

FIRST STAGE, OR ELEMENTARY EXAMINATION.

INSTRUCTIONS.

You are permitted to *attempt* only *eight* questions.

The *first three* questions must be *attempted* by you, and you are then at liberty to select five others from among the remaining questions on the paper.

The value attached to each question is indicated by the numbers at the end of the question.

1. Name the binary compounds which are united to form a piece of limestone. State how these may be separated from one another, and describe the characters presented by each of them. What elements are present in these binary compounds, and what is the general character of each of these elements? (15.)

2. Describe the construction and use of a thermometer, and explain the method by which thermometers are graduated. (15.)

3. Explain, by the aid of a diagram, the mode of origin of springs. How does the water of springs differ from rain-water? (15.)

4. Why is the south-west wind in this country usually accompanied by rain, while the east wind brings dry weather? (11.)

5. Explain what is meant by the 'dew-point.' (11.)

6. What are fiords, and how do you suppose them to have been formed? (11.)

7. Describe the phenomena called *roches moutonnées*, and explain how they are formed. (11.)

8. Draw a sketch-map of Hindustan, showing the position of its great mountain ranges and rivers. (*N.B.*—Names must be given.) (11.)

9. Name six of the minerals which occur most commonly in igneous rocks, and describe their composition. (11.)

10. How is kaolin derived from granite? Describe the several stages of the process. (11.)

11. What is the cause of the interval which elapses between a flash of lightning and its accompanying thunderclap? If this interval, in any particular case, were found to be 11 seconds, what inference would you draw from the fact? (11.)

12. What is meant by the statement that certain forms of life have become extinct? State some of the causes which have brought about the extinction of animals, and name any animals which have become extinct since the appearance of man upon the earth. (11.)

INDEX.

The figures in this Index refer to the *paragraphs*, and not to the *pages* in the book.

PAR.
Actinozoa, 126
Adhesion, nature of, 32; of liquids to solids, 33
Adriatic Sea, shallowness of, 173
Agate, 121
Aggregation, states of, 23
Air, weight of, 3
Alabaster, 123
Alcohol, 31
Alluvial plains, 263
Amber, 56
Ammonia, 213; composition of, 106; in the atmosphere, 213
Amorphous substances, 24
Analysis, explanation of, 21
Andes, earthquakes near the, 161
Aneroïd barometer, 201
Annealing, 26
Anthracite, 126
Arctic Ocean, 174, 273
Athermanous substances, 95
Atlantic Ocean, 171; greatest depth of, 171; floor of, 172; currents of, 182
Atmosphere, elasticity of, 196; height of, 197; weight of, 198; how measured, 199; distribution of pressure of, 202; composition of, 210; vapour in, 211; dust in, 215; not a chemical compound, 216; primary movement of, as a whole, 249
Atmospheric electricity, 274
Atoms, definition of, 22

PAR.
Attraction according to mass, 7
Augite, 122
Aurora, the, 280
Auvergne, extinct craters in, 163
Avalanches, 267

Ball-lightning, 276
Baltic Sea, shallowness of, 173
Barometer, the, 200; as a weather-glass, 207; corrections of the, 208; heights measured by, 209
Binary compounds, 100, 101, 106
Black Sea, shallowness of, 173
Bogs, 141
Bosphorus, the, 191
Bottled sunbeams, 47
Boulder clay, 134; the result of glacial action, 272
Boyle's law, 29
Breakers and their effects, 177
Breccia, 131

Cairngorm, 121
Calcium, 21
Calc-spar, 124
Calms, the region of, 251
Capillary attraction, 34
Carbon, 21, 22, 47
Carbonates, 124
Carbonic acid, 108; in the atmosphere, 212
Centigrade thermometer, 82
Chalcedony, 121
Chalk, 117, 126, 137

PAR.
Chemical action.................. 99
Chemical affinity................ 21
Chemical compounds, breaking up of..............................109
Chemistry, fixed proportions in.....107
Clay........................122, 134
Clay-slate..........................146
Cleavage...........................146
Climate, the conditions which determine, 259; alternations of..283
Clouds, 230; caused by dust, 215; what keeps them suspended.....232
Coal, 126; composition of.........117
Coal-measures.....................167
Cohesion, 21; in liquids.......... 30
Colour, its effects on radiation..... 93
Combustion, 105; nature of, 45; a source of heat................ 97
Compound substances.............100
Compressibility................28, 29
Comrie, earthquakes at...........160
Condensation of vapour...........229
Conduction of heat............... 85
Conductors of electricity.......... 61
Conglomerate.....................131
Convection of heat................ 86
Coral rocks, reefs, and islands— 126, 139, 286
Cornelian..........................121
Crevasses..........................271
Crust of the earth, 112; chemical elements of the.................150
Crystallisation...................... 24
Current induction in electricity.... 73
Currents of the ocean, 178; Sir Wyville Thomson on, 181; of the Atlantic, 182; equatorial, 184; of the Pacific, 189; of the Indian Ocean, 190; of inland seas. 191
Cyclones......................203, 255

Darwin, Mr C., on coral islands, 139; on earth-worms.......285, 286
Decomposition, spontaneous 110
Deformation, resistance to........ 25
Deltas.......................261, 263
Denudation, 260; by the agency of worms...........................286
Depressions of the atmosphere....203
Dew.............................234

PAR.
Dew-point, the....................237
Diamond, the..................... 24
Diathermanous substances......... 95
Dip (in geology)...................151
Doldrums..........................251
Dolomite..........................149
Down, the best non-conductor of heat........................... 87
Drift currents.....................178
Drying day, what makes a........226
Dust, 215; effects of, in the air....231
Dyke (in geology)................129

Earth, overpowering attractive force of, 6; attraction of, upon the moon, 18; a great magnet, 55; interior of, 154; electric currents in.....................279
Earthquake bands.................161
Earthquakes, 160; causes of......162
Earth-worms, as agents of change on the face of the globe.....285, 286
Elasticity......................... 27
Electric light..................... 68
Electric telegraph................. 72
Electricity, 48; frictional, 56; condensed, 64; current, 65; sources of the energy of, 67; connection with magnetism, 69; atmospheric and terrestrial......274
Electrolysis....................... 68
Electro-magnet, the.............. 71
Electroplating.................... 68
Electroscope, the................. 65
Elements, definition of..........22, 99
Endosmose....................... 35
Energy, 36; of moving bodies, 39; how measured, 40; kinetic, 41, 42; potential, 41; molecular, 43–46; always the result of previous work, 47; conservation of.............................. 97
Equinoxes........................283
Erosion by rivers.................262
Ether (the liquid), 31; produces cold by evaporation, 227; ether (the invisible medium).......... 90
Evaporation, 224; ruled by temperature, 225; evaporation produces cold.......................227

PAR.
Expansion by heat, 77, 78; rationale of 80

Fahrenheit's thermometer 82
Falling bodies, the law of 14, 15
Fauna, changes of 284
Felspar 120, 128
Felspathic rocks 261
Fire, nature of 98
Flame, nature of 98
Flint 121
Flood, effects of a 263
Flora, changes of 284
Fog, caused by dust 215
Foliation in rocks 147
Forked-lightning 276
Formulæ for calculating physical and mechanical problems 16
Fossils, a test of the age of strata .. 282
Franklin and the electric spark 276
Frost, disintegration by 261

Galena 125
Galvanic batteries and their effects .. 68
Galvanic current, 65; a magnet 70
Galvanometer 73
Gases, compressibility of, 29; diffusion of 216
Glaciers, 267; move without slope, 269; ancient, 272; the Swiss 283
Glauber salt 24
Gneiss 148
Gradients (in meteorology) 256
Granite 128
Graphite 125
Grauwacke 145
Gravitation, 2; universal, 5; affected by distance, 12; in the'heavenly bodies, 17, 20; general effects of .. 20
Greenland, glaciers in 269
Gulf Stream 181, 185
Gypsum 123, 142

Hæmatite 125
Hail 247
Hard water 265
Heat is motion, 43; expansion by, 77; exceptional case of water, 79; rationale of expansion, 80; specific, 83; importance of specific heat of water, 84; conduction of, 85; convection of, 86; radiation of, 88; latent, 96; sources of, 98; animal, 98; produced by mechanical means, 98; mechanical equivalent of, 98; internal, of the globe 153
Herculaneum 158
Himalayas, snow-line of the 266
Hoar-frost 238
Hornblende 122, 128
Hydrogen, made liquid and solid, 23; rarely found free, 103; combined with oxygen 104
Hydrostatics, basis of the science .. 30
Hygrometers, 228; constructed to show the dew-point 237

Ice, its slow formation and melting, 248; plastic, 268; floes 273
Ice age, the 283
Icebergs 269
Ice-cap (at South Pole), depth of, limited 270
Ice-foot 273
Iceland-spar 124
Indian Ocean, currents of 190
Indraught-currents 183
Induction in electricity, 62; coil 73
Inertia 11
Inland seas 191
Insular climate 259
Insulation 61
Iron ores, where found 125
Ironstone, blackband 125
Isobars 204
Isothermobathic lines 192

Japan Current, the 189, 195

Kaolin 261
Kendal, rainfall at 242
Khasia Hills, rainfall at 242, 243
Kinetic energy, 41; converted into heat 42

Labrador Current, the 187
Land, changes in conformation of .. 282
Landslips 262
Latent heat, 96; not lost 97

PAR.
Lava, nature of, 31; recent....... 127
Lava-streams....................... 156
Levelling, by the agency of worms.. 286
Lightning, 276; and electric spark. 64
Lightning-conductors............. 278
Limestone, 137; analysis of, 21; compact, 138; crystalline, 149; action of water on, 264; carried into the sea by rivers............ 265
Liquid state, 23; cohesion in...... 30
Lisbon, earthquake at............. 160
Loadstone, the.................... 49
Loam............................. 135
London, rainfall at............... 242
Luminous rain..................... 278

Magnetic induction, 53; storms... 279
Magnetism........................ 48
Magneto-electric machines........ 74
Magnets, natural and artificial, 49, 50; by galvanic current......... 70
Marble, analysis of, 21; saccharoid. 149
Mariner's compass............ 54, 281
Marl.............................. 135
Mass and weight.................. 8
Maxwell, Professor J. C., on the connection between electricity and light and heat.............. 90
Mediterranean Sea, depth of, 173; evaporation of, 191; temperature of.......................... 192
Mercury, specific heat of.......... 83
Metals, ores of................... 125
Metamorphic rocks................ 144
Meteors.......................... 197
Mica............................. 120
Microphone....................... 279
Minerals.................... 120–126
Mistral.......................... 254
Molecular energy, 44; potential... 46
Molecules, definition of........... 22
Monsoons......................... 253
Moon, and the earth's attraction... 18
Moraines, 271; submarine......... 272
Mosses........................... 141
Mozambique Current.............. 190
Multiple proportions in chemistry.. 108

Névée, a......................... 267
New South Wales Current........ 189

PAR.
Newton's law of gravitation....... 19
Nordenskjöld..................... 181

Ocean, the, 174; horizontal circulation of, 178; vertical circulation of, 178; density of........ 194
Oolite........................... 137
Ores of metals................... 125
Osmose.......................... 35
Oxides........................... 105
Oxygen, 21, 47; production of, 102; combined with hydrogen, 104; in the earth's crust......... 150
Ozone............................ 214

Pacific Ocean, greatest depth of, 171, 173; North, 174; currents in............................... 189
Pack ice......................... 273
Peat...................... 126, 141
Peru, rainless slopes of.......... 245
Pietermaritzburg, lightning-rods at.............................. 278
Pipe-clay........................ 134
Plains, alluvial.................. 263
Platinum, expansibility of........ 78
Polar seas, 173; lights.......... 280
Polarity......................... 51
Potential energy................. 41

Quartz, 120, 121, 145; crystals.... 24
Quartzite........................ 145
Quaternary compounds............ 100

Radiation of heat, 88; effect of colour on, 93; loss of heat by.... 99
Rain, the greatest falls of, 240; luminous........................ 278
Rainfall in different regions, 242; extraordinary.................. 243
Rain-gauge...................... 241
Rainless regions................. 245
Raised beaches................... 165
Ravines, how made............... 262
Réaumur's thermometer........... 82
Red Sea, temperature of.......... 193
Rhine, lime carried into the sea by.. 265
Rio Janeiro, rainfall at.......... 242
Rivers, erosion by............... 262
Rocks, 113–149; composition of,

PAR.

113; classification of, 114; sedimentary, 115; chemically formed, 116; organic, 117; metamorphic, 118; unstratified................119
Rock-salt........................142
Roscoe on the elements of the earth's crust....................150
Runn of Kutch, the great.........164

Saccharoid marble................149
Salt, common.....................169
Sandstone.................115, 132
Sargasso Sea.....................188
Satin-spar.......................123
Schists..........................147
Sea, bottom, depth, and form of, 171; surface temperature of, 193; influence of on climate, 195; changes in the conformation of...282
Sea-and-land breezes.............252
Sea-water, composition of.........169
Serpentine.......................122
Shale............................133
Sheet-lightning..................276
Siam, temperature of sea at.......193
Sierra Leone, rainfall at.........242
Silicates........................122
Singapore, rainfall at............242
Sinter, silicious................143
Sirocco..........................254
Skaptur Jŏkul....................156
Snow......................87, 246
Snow-line........................266
Sodium, chloride of..........169, 285
Sodium sulphate.................. 24
Soil, the superficial.............136
Solid state...................... 23
Specific gravity.................. 9
Spectrum, the.................... 89
St Elmo's fire....................278
Stalactites..............116, 124, 143
Stalagmites...............124, 143
Storms, 255; centre of, 257; motion of, as a whole, 258: magnetic....279
Strain........................... 25
Strata, disposition of............151
Submerged forests................166
Subsidence, causes of.............168
Sulphates........................123
Sun the great source of energy..... 47
Syenite..........................128
Synthesis........................ 21

Talc.............................122
Telegraph Plateau, the...........172
Telephone........................279
Temperature of ocean, circulation caused by, 179; theory disputed, 180; band of uniform, 192; of atmosphere, distribution of, 217; of equator, 218; effects of elevation on, 219; effects of isolation on, 220; effects of expansion on...........................221
Tenacity......................... 26
Ternary compounds................100
Terrestrial electricity...........274
Thermometer, its construction, 81; different kinds of the, 82; uses of the, 223; the dry-and-wet-bulb..........................228
Thomson, Sir Wyville, on the temperature of the waters of the ocean, 192; on the Polar basin..273
Thunder-storms...............275, 277
Till.............................272
Tornea, subsidence of land at.....168
Torricelli's experiment with mercury.........................200
Trade-winds, 250; the return......250
Translation, movement of.........175
Trap-rocks.......................127
Travertine.......................143
Tropics, effects of the sun at.....179
Twilight.........................197
Tyndall, Prof., researches on heat.. 95
Typhoons.........................258

Unconformability.................152
Upheaval, causes of..............168

Vapour, 211, 225; its effect on atmospheric pressure............202
Velocity caused by gravity........ 15
Vesuvius, eruption of.............158
Virgin Islands, depth of sea at....172
Viscosity........................ 31
Volcanic ash, 157; steam.........158
Volcanoes, 155, 159; causes of, 162; extinct..................

PAR.
Water, crystallised, 24; expansion and contraction of, 79; absorption of heat by, 83; a bad conductor, 86; composition of, 105; hard...265
Waves, 175; cause and velocity of...176
Weathering...261
Weight, difference of, at the poles and the equator... 8
Winds, origin of, 249; the trade, 250; periodical, 253; variable...254
Wool... 87
Work, how measured... 37
Worms, as agents of change on the face of the globe...285, 286

Yellow Sea, shallowness of...173

Zinc, expansibility of... 78

THE END.

Edinburgh:
Printed by W. & R. Chambers.

CHAMBERS'S EDUCATIONAL COURSE

NEW READING-BOOKS

EDITED BY J. M. D. MEIKLEJOHN, M.A.

PROFESSOR OF EDUCATION IN THE UNIVERSITY OF ST ANDREWS.

ENGLISH READING-SHEETS. Illustrated. 14 Sheets......each 3d.

	Pages.	*Woodcuts.*		*s.*	*d.*
ENGLISH READER, PRIMER I	32	38	cloth	0	2
ENGLISH READER, PRIMER II	66	58	"	0	3
ENGLISH READER, BOOK I	96	37	"	0	6
ENGLISH READER, BOOK II	128	37	"	0	8
ENGLISH READER, BOOK III	192	40	"	1	0
ENGLISH READER, BOOK IV	288	48	"	1	6
ENGLISH READER, BOOK V	384	50	"	2	0
ENGLISH READER, BOOK VI	416	52	"	2	6
HOME LESSON BOOK for English Reader, Book I				0	1
HOME LESSON BOOK for English Reader, Book II				0	1

These books have been prepared to meet the requirements of the Code, are carefully graduated, printed in large clear type, and strongly bound.

STANDARD READING-BOOKS, *Illustrated.*

	s.	*d.*
Alphabet Sheet, on strong board	0	6
Infant School Reading-Sheets. In 14 sheets......each	0	1
Primer, Part I. sewed, 1½d.; also in limp cloth	0	2½
Primer, Part II	0	3
First Standard Reading-Book	0	6
Second Standard Reading-Book	0	8
Third Standard Reading-Book	1	0
Fourth Standard Reading-Book	1	2
Fifth Standard Reading-Book	1	4
Answers to the Arithmetical Exercises in the Standards	0	6
Poetical Gleanings	1	0
Short Stories, for Standard V., First and Second Series...each	1	3
Literary Reader, for Standard VI	1	6

NATIONAL READING-BOOKS, *Illustrated.*

National Reading-Sheets. In 16 sheets......each	0	1
———— 16 Sheets on 8 boards...... "	0	6
National Primer, Step I. 1d.; also in large type, 1½d.; Step II.	0	3
First National Reading-Book	0	6
Second National Reading-Book	0	8
Third National Reading-Book	1	0
Fourth National Reading-Book	1	6
Fifth National Reading-Book	2	0
Sixth National Reading-Book	2	6
Girls' Reading-Book, in three parts, each 6d.; in 1 vol	1	6

ENGLISH.

First Book of Reading, *sewed*	0	1½
Second Book of Reading, "	0	3
Simple Lessons in Reading	0	8
Rudiments of Knowledge	0	8
Lesson Book of Common Things and Ordinary Conduct	0	8
Spelling Book, in three parts, 1½d. 6d. and 6d.; also in 1 vol...	1	0
Spelling Vocabulary	0	6
Moral Class-Book	1	6
Composition, Introduction to	0	6

CHAMBERS'S EDUCATIONAL COURSE—*continued.*

ENGLISH—*continued.*

	s.	d.
Standard Grammar, Book I., for Standard II.	0	2
————, Book II., for Standard III.	0	3
————, Book III., for Standard IV.	0	3
Grammar, Introduction to	0	6
Grammar and Composition	1	6
Narrative English Grammar, *sewed*, 4d.; *cloth*	0	6
Practical English Grammar	1	0
Etymology, Exercises on	2	0
Elocution, Principles of	2	6
History of English Language and Literature	2	0
Etymological English Dictionary	4	0
Sentences for Analysis	0	3
Rules for Paraphrasing	0	4
Synthetical Structure of Sentences	0	6
Friendly Advice to Pupil-teachers	0	4
Problem of Teaching to Read	0	6
Readings in English Prose	2	0
———— Poetry	2	0
———— Literature	3	6
Class-book of Science and Literature	3	0
Kindness to Animals	1	6

WRITING AND DRAWING.

	s.	d.
Post Copy-Books, in 15 Nos. each	0	6
Foolscap Copy-Books, in 14 Nos „	0	2
Copy Lines, Nos. 1 to 12 „	0	4
Graduated Writing-Sheets, Nos. 1 to 15 „	0	2
Freehand Drawing. First Grade—Elementary	1	0
———— „ „ —Advanced	1	0
———— Second Grade	2	0
First Book of Drawing, 1s.; or in two parts, *sewed* each	0	4
Second Book of Drawing	1	0
Drawing Books, Progressive, in 18 Books, *sewed* each	1	6
Mechanical Drawing, in 3 Books, *sewed* „	1	6
Architectural Drawing, in 3 Books, „ „	2	0
Isometrical Drawing, in 2 Books, „ „	2	0

GEOGRAPHY.

	s.	d.
Geographical Primer	0	6
Standard Geography, in 4 parts, 2d. each; cloth, 3d.; in 1 vol.	1	0
England, Geographical Text-Book of	0	9
Scotland, Standard Geography of, with Map	0	4
Scripture Geography, Text-Book of	0	10
Elements of Physical Geography	1	0
Standard Physical Geography, 3d.; cloth	0	4
Outline Maps, 16 in a wrapper	1	6
Or separately, folio, 2d.; quarto, 1d. each.		
LARGE SCHOOL-ROOM MAPS (5 ft. 2 in. long, by 4 ft. 6 in. broad), nine, each mounted (or varnished, 2s. extra)	12	0
The Hemispheres, mounted (or varnished, 2s. extra)	18	0
School Wall-Map of the World	£1 1	0
Atlas of Europe, containing 13 quarto Maps	0	6
Sixpenny Atlas, consisting of 16 octavo Maps	0	6
Primer Atlas, consisting of 14 quarto Maps	2	0
School Atlas, consisting of 31 quarto and 3 folio Maps	5	0

CHAMBERS'S EDUCATIONAL COURSE—*continued.*

HISTORY.

	s.	d.
Ancient History	2	6
Medieval History	3	0
Modern History	3	6
History of Ancient Greece	2	6
History of Rome	2	6
Short History of England, Part I. 2d.; Part II. 3d.; Part III.	0	6
Or in 1 vol.	1	0
History of the British Empire	2	0
English History, Leading Events in	1	6
Or, Part I. 6d.; Part II. 1s.		
History of Scotland	1	6
Questions and Answers on British History	1	0
France, its History and Revolutions (*School Edition*)	2	6
Biography, Exemplary and Instructive	2	0
Historical Questions, with Answers	2	6
Historical and Miscellaneous Questions, with Answers	4	6

ARITHMETIC AND MATHEMATICS.

	s.	d.
Standard Arithmetical Exercises, by H. Allen, Taunton. Adapted to the requirements of the New Code.		
Standards I. to III. each, *sewed*, 2d.; *cl.* 3d. Answers, *cl.*	0	4
Standard IV. " 2d.; " 3d. Answers, "	0	4
Standard V. " 3d.; " 4d. Answers, "	0	3
Standard VI. " 4d.; " 5d. Answers, "	0	3
Arithmetical Exercises, by John S. Mackay, M.A.		
Parts I. to IV. each, *sewed*, 1½d.; *cloth*,	0	2½
Part V. " 4d.; "	0	5
The above Five Parts in One Volume, 1s.; Answers to	0	6
Arithmetical Exercises, by J. S. Mackay, M.A. Standards I. II. III. (Scotch Code), each 1½d.; Answers to	0	3
Arithmetic, Introduction to	1	0
——— Advanced Treatise, 2s.; Key to	2	0
National Arithmetical Test Cards. Six Packets. Price 9d. each in paper cover; in cloth case	1	0
Book-keeping by Single and Double Entry	1	6
——— by Single Entry	1	0
——— two Ruled Paper Books for Single Entry, *sewed*	1	3
——— two Ruled Paper Books for Double Entry, "	1	3
——— Transactions in, by Single and Double Entry	0	6
Questions in Book-keeping, with Answers	1	6
Farm Book-keeping *sewed*	0	6
Standard Algebra, Parts I. and II. each 3d.; Parts III. and IV. each 6d.; or in 1 vol. 1s. 6d.; Answers	0	8
Algebra, Theoretical and Practical, 2s. 6d.; Key to	2	6
Exercises and Problems in Algebra, with Answers	2	0
——— without Answers	1	0
Plane Geometry, *sewed*, 1s.; *cloth*, 1s. 6d.; Key	2	0
Explicit Euclid, 2s.; Key	2	0
——— Books I. and II. 4d.; Books III. and IV.	0	4
Geometrical Chart—measuring 3 ft. 4 in. by 2 ft. 4 in.	2	6
Solid and Spherical Geometry	1	6
Mensuration of Lines, Surfaces, and Volumes	1	6

CHAMBERS'S EDUCATIONAL COURSE—*continued.*

ARITHMETIC AND MATHEMATICS—*continued.*

	s.	*d.*
Exercises on Mensuration, forming Key to Mensuration	2	0
Practical Mathematics, 3s. 6d.; Key	3	6
Mathematical Tables	4	6
Trigonometrical Tables	1	6

SCIENCE.

Introduction to the Sciences	1	0
Laws of Matter and Motion	0	10
Mechanics, Elementary	3	0
Scientific Reader	2	0
Practical Chemistry, by Dr S. MACADAM	2	6
Inorganic Chemistry, by Professor WILSON	4	0
Analytical Chemistry	1	6
Domestic Economy, Parts I. and II. each 2d.; Part III	0	3
Or in 1 vol	0	10
Study of Flowers. By Dr WILSON	0	6
Standard Animal Physiology. *New Edition.* By Dr WILSON. Part I. 2d.; Parts II. and III. each 3d.; or in 1 vol	1	0
Miscellaneous Questions, with Answers	2	6
Electricity, by Dr FERGUSON	3	6
Scientific Charts—		
Sheet 1. Matter and Motion, 1s. 6d.; 2 & 3, Mechanics, each	1	6
Each sheet mounted on rollers, 4s. 6d.; varnished	5	6

LATIN.

	s.	*d.*
Ruddiman's Latin Rudiments	0	10
Latin Grammar, Elementary	2	0
——, Advanced	4	0
Latin Exercises, Elementary	1	6
——, Advanced	2	6
—— Key to Advanced	2	0
Phædrus's Fables	1	6
Nepos	2	0
Cæsar	2	6
——, Book VII	0	6
Sallust	1	6
Quintus Curtius	3	0
Ovid	3	0
Horace	3	0
Virgil — Bucolics, and Æneid I. to VI.	3	0
Virgil—Æneid, Book VII.	0	3
——, Book IX.	0	3
Livy	3	0
Latin Dictionary	6	0
—— Latin-English Part	3	6
—— English-Latin Part	3	6

GERMAN.

First German Reading-Book	1	6
Second German Reading-Book	2	6
German Grammar, Elementary	1	6
——, Advanced, 3s.; Key	1	6
English-German Phrase-book	1	6
German Dictionary, German and English	6	0
—— German-English Part: English-German Part......each	3	6
Dictionary of German Synonyms	1	6

MINOR EDUCATIONAL COURSE.

1. Introduction to Reading	1½d.
2. Reading Lessons	1½d.
3. Arithmetical Primer	1½d.
Answers to do.	1d.
4. Grammatical Primer	1½d.
5. Outlines of Geography	1½d.
6. History	1½d.
Or in 1 Vol. (*Without Answers*).	1s.